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A REVIEW OF 34 CONSECUTIVE CASES OF PNEUMONECTOMY, WITH AND WITHOUT CONCOMITANT THORACOPLASTY, IN THE TREATMENT OF TUBERCULOSIS

JOHN L. SHEK, M.D.,* AND GORDON D. MYERS, M.D.**
ROME, GA.

GREAT strides have been made in the surgical treatment of pulmonary tuberculosis since the concept of resection was brought into the recent literature by Freedlander,[1] in 1935. Jones and Dolley,[2] Janes,[3] and Sweet[4] followed up with reports of lobectomy and pneumonectomy in the treatment of tuberculosis in the ensuing ten years. Overholt[5] and Chamberlain[6] and their associates, applied the knowledge of segmental anatomy of the lung in the resection for the disease, as Churchill and Belsey,[7] and Blades[8] had first made use of it in excisional surgery for bronchiectasis. With the improved knowledge of anesthesia, blood transfusion, pulmonary physiology and anatomy, thoracic surgery, the introduction of antituberculous drugs, and a better concept of tuberculous pathology, pulmonary resection of different magnitude has well established itself as another definitive surgical treatment for tuberculosis. Attention, therefore, has been focused more toward the refinement of surgical technique and postoperative care to improve further the already noteworthy results.

Literature has been abundant with reports of series of cases of resection for the treatment of pulmonary tuberculosis. It has become apparent that the most dreaded complication and the major cause of postoperative, and even delayed mortality, is the notorious bronchopleural fistula. Although faulty technique in the closure of the bronchus stump could, and does, occasionally account for the fistula formation, it is, however, agreed that the intrinsic disease

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*Chief of Surgery, Battey State Hospital, Rome, Ga.
**Resident in Thoracic Surgery, Battey State Hospital, Rome, Ga.

in the bronchial wall and infection in the pleural space surrounding the amputated stump are responsible for its incidence in most cases. It has also become increasingly clear that failure to properly cope with the residual pleural space following resection of lung tissue usually precedes this complication. Thoracic surgeons working in this field have employed various means to handle the residual space, but no single solution has been agreed upon as yet. Many have explored the use of foreign body prosthesis, intrapleurally, extrapleurally, or extramusculoperiosteally, such as oil, Sirconium, Lucite sphere, Gelfoam, Ivalon sponge, cellulose, Neoprene, Polyvinyl sponge, etc.[9-17] Some used air in the form of pneumothorax and pneumoperitoneum. These either have a limited usefulness, the acceptance has been controversial, or they have been proved to be undesirable. The only other recourse left to cope with the residual pleural space for the sake of lowering the likelihood of bronchopleural fistula and prevention of overdistention of the remaining lung tissue, ipsilateral and/or contralateral, lies in the versatile thoracoplasty. There are many varied opinions regarding the desirability of thoracoplasty in conjunction with pulmonary resection. This paper is concerned only with the concomitant thoracoplasty and pneumonectomy.

Graham, in 1933, performed the first successful pneumonectomy and concomitant thoracoplasty. Iverson and Skinner[18, 19] reported its use in pulmonary tuberculosis. Samson,[20] Conklin,[21] and Cruickshank[22] and their associates followed with reports of encouraging results in selected cases. The advantages of the one-stage operation are well elaborated upon by these authors in their original articles. However, because of the greatly increased morbidity, such combined procedure has not gained general acceptance and its usefulness is, therefore, limited to strictly selective cases. However, we believe that this procedure is stigmatized without being duly investigated.

This paper reports a comparative study of 17 cases of pneumonectomy and concomitant thoracoplasty and another 17 cases of pneumonectomy without concomitant thoracoplasty performed consecutively over a period of 21 months, ending February, 1955. From a review of the various data, the authors are not particularly impressed with the increased morbidity in the postoperative period. In fact, it is felt that the postoperative course is comparatively more benign than in operations for primary pneumonectomy done without concomitant thoracoplasty. An attempt is made first to establish the fact as to whether the two groups are of comparable composition regarding the factors of race, age, sex, extent of disease, activity of lesion, and length of preoperative antibiotic treatment, etc. The two groups are then compared as to their operative and postoperative morbidity. Various favorable features of the combined procedure are also noted.

TECHNIQUE

The face-down position is used. The anesthesia consists of Pentothal sodium and Anectine induction with endotracheal intubation as soon as possible, and supplemented with nitrous oxide, oxygen mixture, and intravenous drip Anectine. Exposure is gained

through the usual posterolateral incision and the pleural cavity is entered through fifth rib bed. Great caution is exercised in avoiding rupture into the tuberculous cavity and extrapleural dissection is used extensively, if necessary, without concern about maintaining an intact parietal pleura. Oozing from the raw surface of the chest wall is usually stopped by warm saline packs and this often ceased after removal of the ribs. The lung is resected in the usual fashion. At this time, the general condition of the patient is estimated and the blood loss calculated by the sponge weighing technique and the operative time is surveyed. If the patient's condition is satisfactory, local intercostal nerve block with one per cent procaine was carried out prior to subperiosteal resection of the second down through the seventh ribs. Posteriorly, the resection starts from within the lateral margin of the spinalis group of muscles, at times from the level of the transverse processes, anteriorly, to the midclavicular line of the second rib, in diminishing lengths to the seventh rib, which is around the scapular line, so as to allow the shoulder blade to fall in without any impingement. The usually shredded intercostal muscle bundles are then repaired to re-form a more or less complete partition between the pleural space and the subscapular space. A certain amount of tailoring is done to these bundles to reduce the size of the residual pleural space. One intercostal drainage tube is left inside the space connected to a underwater seal system. A tight dressing with a roll of cotton padding over the decostalized portion of the chest wall under the axilla is then applied to further immobilize the side and reduce the amount of possible mediastinal fluttering. Adequate tracheobronchial aspiration is then done, usually without the necessity of bronchoscopy.

There is no special feature in the postoperative care. Primary attention is paid to the amount of drainage, which is measured, and the blood loss is adequately replaced. The tube is left in for 24 to 48 hours and longer in cases where contamination is suspected. The pressure dressing sometimes is necessary for about two weeks, postoperatively.

This is a series of 34 pneumonectomies done consecutively between May, 1953, until February, 1955, during which time a total of 225 resections of various extent were done, a percentage of 15.1. These patients, therefore, all have had a postoperative follow-up of at least 9 months. We are quite aware that due to the miraculous effect of antituberculous drugs in a majority of cases, total resection of lung has become less and less indicated. With the improvement of surgical technique, most of the cases that would have called for a pneumonectomy in the earlier days of surgical excision now require only lobar, or lobar and segmental resection. However, all the patients in this series had a totally destroyed lung without a single segment that was worth salvaging. They all had had bilateral involvement at one stage. The less involved side not infrequently had had cavitary disease, but those cases had improved and stabilized, while the side with the major involvement progressed on to a stage of total destruction in a few cases, either in the form of residual giant air-containing cystic remnant of lung, or, more often, to a unilocular or multilocular cavitary residue with patches of pneumonic changes. Most of these cases were considered to be only salvageable. Table I will show the distribution of cases in the two groups, one with concomitant thoracoplasty and the other with nonconcomitant thoracoplasty. In the nonconcomitant group, there were 2 thoracoplasty failures, one plombage failure, one primary pneumonectomy with postresection thoracoplasty, and 13 cases with preresection thoracoplasty. (The advantages of preresection thoracoplasty have been elaborated upon in another communication.)[23]

TABLE I

	NUMBER OF CASES	SEX		RACE		AGE GROUP				AVERAGE LENGTH OF DISEASE YEARS
		M	F	WHITE	NEGRO	16-19	20-29	30-39	40-49	
Combined procedure	17	2	15	5	12	4	8	4	1	3.7
Separate procedure	17	5	12	5	12	0	7	6	4	4.4

From Table I, it became at once apparent that the two groups are closely comparable as to the distribution of sex, race, and the average duration of disease, which was measured from the date when the diagnosis of pulmonary tuberculosis was established until the date of definitive operation. It indicates that, although the majority of patients in either group lies within the third and fourth decade of life, there was a tendency of the group with the combined procedure to be in the younger age limit.

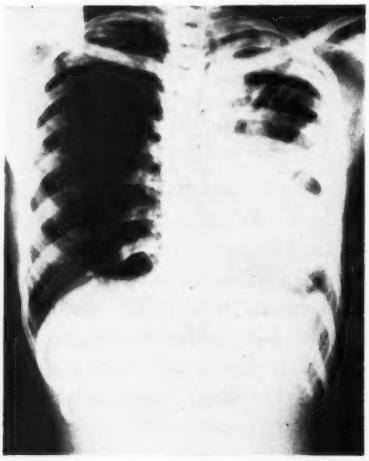

Fig. 1.

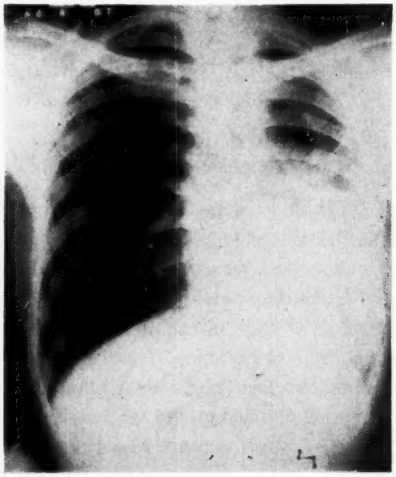

Fig. 2.

Fig. 1.—Case No. 22. P. W., a 37-year-old Negro woman, was admitted Nov. 10, 1950, far advanced, D. She received 14 months of streptomycin and para-amino-salicylic acid (PAS), and 14 months of isonicotinic acid hydrazide (INAH) and PAS, preoperatively. Combined pneumonectomy and thoracoplasty were performed on Feb. 2, 1954, with uneventful recovery. The sputum positive, Jan. 22, 1954, and converted immediately and has remained so since. The specimen shows destroyed lung with three large cavities, active endobronchitis, and caseous bronchopneumonia. The patient was discharged home, Dec. 28, 1954.

Fig. 2.—Case No. 11. W. H. W., a 26-year-old Negro man, was admitted Sept. 8, 1952, far advanced, C. He received 12 months of streptomycin and PAS, and six months of INAH and PAS, preoperatively. A combined procedure was performed on Oct. 21, 1954, with smooth recovery. The sputum was positive last on Feb. 18, 1954, and has remained negative since. Specimen shows healed cavity with destroyed lung and no active tuberculosis. He was discharged April 26, 1955.

The following table (Table II) compares the degree and variety of pathologic processes from the resected specimens in both groups. It shows that the two groups also have more or less similar data. In Table II, by active disease we mean that there is definite active tuberculous process in the form of either

cavitation, granulating tissue, endobronchial disease, or even caseous pneumonic process. The expression inactive disease is used to designate lack of such findings, as well as cases where only dormant fibrocaseous residue was present. Instances where only the controversial "healed cavity" or giant air-containing spaces of the lung were found are also regarded as inactive disease.

TABLE II

	PATHOLOGIC PROCESS		BACTERIOLOGY OF RESECTED SPECIMEN					
	ACTIVE DISEASE	INACTIVE DISEASE	D. S. +	CUL. +	D. S. +	CUL. −	D. S. −	CUL. +	D. S. −	CUL. −
Combined procedure	13	4	7		5		1		4	
Separate procedure	15	2	8		6		1		2	

D. S. = direct smear.
CUL. = culture.

This was especially considered to be so when bacteriologic studies failed to show presence of tubercle bacilli. No special technique was employed to cultivate the bacteria, although some of them were incubated for a longer period of time than the routine six weeks. Again, the data in Table II does not show any striking difference in results in the 2 groups.

Fig. 3.—Case No. 27. R. L. S., a 28-year-old white woman, was admitted Sept. 28, 1945, far advanced, D. She received numerous courses of various combinations of streptomycin, INAH, and PAS, preoperatively. Left anterior and posterior Monaldi drainage was performed on Aug. 20, 1948; combined procedure on Jan. 26, 1955. The patient had transient cor pulmonale for two weeks. The anterior Monaldi wound broke down and healed in five months. Sputum was positive on Jan. 24, 1955, and has converted since. Specimen shows destroyed lung with large lower lobe cavity, bronchiectasis and active endobronchitis. The patient is now in process of being discharged.

In respect to preoperative antituberculous drug therapy, all 34 patients have received treatment in various combinations over a period of time, averaging 26.1 months, with 2 cases of six months' duration and 3 cases over three years. A minimum of eighteen months of drug therapy followed the resection. Bacteriologically, drug resistance assay was done in 23 of the 34 cases and

showed the usual pattern of conversion of organisms into resistant strains. Nineteen patients had preoperative conversion of sputum, with an average length of about 14.2 months before surgery. The sputum of 12 patients was converted directly and immediately after surgery, and in 2 converted six and seven months, respectively, subsequent to resection. Only in one case (2.9 per cent) has it remained persistently positive to culture, apparently from an ulcerated bronchial stump, diagnosed bronchoscopically. It has remained refractory to both internal and local therapy.

The average follow-up of these 34 cases is 19.3 months, ranging from 9 months to 32 months, postoperatively. To date, one patient, in the noncombined-procedure group, died of acute fulminating tuberculous pericarditis (2.9 per cent). The lone case of mortality involves a white man of 40, who had failed to show the anticipated amount of improvement under active medical regime and continued to run a downhill course with repeated bouts of hemoptysis. A Lucite ball plombage was performed and it improved the patient's general condition to a certain extent, but repeated hemoptysis later justified an emergency pneumonectomy. The patient improved and did well for three months, postoperatively, but died in the fifth month postoperatively of acute fulminating tuberculous pericarditis. This patient's sputum was converted directly after resection and remained so until the time of death. There was no death in the combined-procedure group.

As to the present status of the remaining 33 patients who are still alive, Table III will show that 28 patients are well and have been discharged home with negative sputum. Of the 5 patients who are still hospitalized, all are in the combined-procedure group. Three of them are being processed for discharge home as arrested cases of pulmonary tuberculosis, including the one with miliary and meningeal involvement. The remaining 2 still face an uncertain future, one with multiple incisional sinuses as a result of an infected subscapular space, secondary to bronchopleural fistula and empyema, and the other with an infected bronchial stump refractory to local and general treatment. The latter also has a positive sputum. Therefore, out of 17 cases with concomitant procedure, 2 are still hospitalized; one with positive sputum.

TABLE III

	NUMBER OF PATIENTS	LENGTH OF TIME (POSTOPERATIVELY)		SPUTUM ANALYSIS (POSTOPERATIVELY)
Discharged home	28	Within 6 months	6*	All negative
		Within 9 months	10	
		Within 12 months	12	
		Within 15 months	1	
Hospitalized, but in process of being discharged	3	(a) 7 months		(a) Negative 7 months
		(b) 8 months		(b) Negative 8 months
		(c) 13 months		(c) Negative last 8 months
Hospitalized, but not likely to be discharged soon	2	(a) 11 months		(a) Negative for last 5 months
		(b) 13 months		(b) Positive to date

*1 against medical advice; 1 disciplinary discharge.

The findings so far tabulated indicate that the two groups of patients who have had a pneumonectomy can be closely compared with regard to sex, race, age group, extent of disease, activity of disease, length of illness prior to surgery, and length of preoperative and postoperative chemotherapy. It would, therefore, seem worth while to make a comparison of the operative and postoperative morbidity in the two groups in an effort to uncover some indication as to whether the concomitant procedure is as risky an operation as it is reputed to be.

From the data in Table IV, which listed postoperative complications, there is no predominance of morbidity rate in either group. The 2 cases of prolonged low-grade fever, lasting for about one month postoperatively, are believed to be due to a tuberculous process in the mediastinal lymph nodes which subsides under treatment with antibiotics without consequence. The one bronchopleural fistula, which developed in the second week, postoperatively, was treated with revision thoracoplasty, including resection of transverse processes, in the third week. The fistula apparently closed in the fourth week, but the subscapular infection persisted, leaving behind draining sinuses along the incision at the present time. The sputum, however, converted six months, postoperatively, and has remained so since then, which is about five months. One patient developed a localized tuberculous abscess along the incision and healed after incision and drainage and topical application of isonicotinic acid hydrazide (INAH) solution. All 4 patients who developed transient episodes of right heart failure had extensive bilateral involvement and one of them had miliary tuberculosis and proved meningitis. They all responded readily to digitalization and other supportive measures and recovered within one to two weeks. One, who had had both anterior and posterior Monaldi drainage done seven years before, had the anterior wound break down after the resection. It healed after five months of local treatment. All patients had some degree of hyperpnea, and a few had dyspnea in the first 48 hours, but none were cyanotic for more than a few minutes. The tuberculous pericarditis occurred in the fourth month, postoperatively, in the patient who eventually died in the fifth month. The data of these late postoperative complications, therefore, compare favorably between each group. Upon reviewing the literature, it is noticed that they compare quite well with that of O'Brien and his co-workers,[24] who reported a series of 49 pneumonectomies for tuberculosis done between 1947 and 1952, with a morbidity rate of both early and late complications of 43 per cent and five deaths. McBurney and his associates[25] reported 20 cases of pneumonectomy for tuberculosis performed through December, 1952, with complications in 13 patients, 3 had bronchopleural fistulas, and there were three deaths. Baffes and associates,[26] reviewed 72 pneumonectomies done between 1942 and 1951, and found 14 deaths, 3 cases of empyema, and 7 of spread. Although it is realized that these reports concern operations performed in the earlier days of pulmonary resection for tuberculosis, it is felt that in spite of the limited size of this series done between May, 1953, and February, 1955, that the postoperative morbidity does not compare unfavorably with pneumonectomy done without concomitant thoracoplasty.

TABLE IV

	TOTAL NUMBER	LOW-GRADE FEVER	LOCAL ABSCESS	BRONCHO-PLEURAL FISTULA AND EMPYEMA	COR PULMONALE	SPREAD	WOUND INFECTION	DRAINING SINUS	MONALDI WOUND	TUBERCU-LOUS PERI-CARDITIS
Combined procedure	3 (17.7%)	0	1	1*	2	1*	1*	1*	1	0
Noncombined procedure	5	2	0	0	2	0	0	0	0	1
Total	8 (23.5%)									

*Same patient.

As to the operative morbidity of this combined procedure, which is reputedly higher than those procedures without concomitant thoracoplasty, we have also failed to find significant difference between the two groups. The following tables (V and VI) are compiled from the anesthesia chart, the progress notes, and the nurses' bedside notes. Table VII will show the computed average of each item from Tables V and VI.

Anesthesia time was used as it is more accurately and constantly recorded than the actual beginning of the operative procedure. It is interesting to observe from the anesthesia chart that the blood pressure usually runs a constant level until actual subperiosteal resection of ribs, second to include the seventh, began. This additional procedure, which usually takes about 15 minutes to 20 minutes, seems to be responsible for a drop on an average of 15 mm. Hg and also a loss of another 200 to 300 c.c. of blood. The pulse rate usually rises on an average of 10 points per minute. These changes in the general condition of the patient, however, do not appear to be of great significance nor serious enough to be called an increase in the operative morbidity. Iverson[19] reported, "Blood is administered during operative procedure in amounts up to 1,500 c.c. and continued after operation up to 2,000 to 2,500 c.c." Our series shows an average of 2,600 c.c. administered in the operating room, and another 700 c.c. after the operation. An average of 1,250 c.c. of blood loss in the drainage bottle was measured in the postoperative period. The drainage usually stops entirely within the first 24 hours. We have not encountered any case of profound shock and in no instance was a drop in blood pressure not immediately responsive to acceleration of the blood transfusion rate in replenishing the blood level. Because of the necessity of the patient to readjust to the loss of the pulmonary vascular bed of one lung, though destroyed in respiratory function, the blood transfusion was given at a slow rate and no incident of pulmonary edema was encountered.

As to the other features in the post pneumonectomy care of the patients, it is gratifying to note that in agreement with Iverson's findings, no bronchoscopic aspiration was found necessary in this series. In fact, this is the most impressive feature of the postoperative period. All patients have an effective cough mechanism and no atelectasis of part of the contralateral lung has occurred. Only a few needed tracheal aspiration, especially those who had had a transient episode of right heart failure. All patients, however, do have some degree of hyperpnea which is not any more pronounced than in those having had a primary pneumonectomy. They usually became comfortable after the first 24 to 48 hours.

Another one of the remarkable features of the postoperative period of such combined procedure is the total "freedom" from concern of a shifted mediastinum and swing. Most of us will agree that in addition to the blood loss and, therefore, shock in pneumonectomized patients, the main complication most dreaded is the mediastinal displacement in the immediate postoperative period. Many a death can be directly traced to this mechanical displacement of the mediastinum with its train of serious, if not fatal, alteration of cardiorespiratory physiology. It is our feeling that in cases with concomitant thoracoplasty,

TABLE V. CASES WITH CONCOMITANT PROCEDURES

NAME AND CASE NUMBER	ANESTHESIA TIME		ALTERATION OF BLOOD PRESSURE AND PULSE DURING OPERATION	BLOOD LOSS DURING OPERATION (C.C.)	BLOOD GIVEN DURING OPERATION (C.C.)	SUBSEQUENT BLOOD GIVEN (C.C.)	BLOOD LOSS IN DRAINAGE BOTTLE (C.C.)	TUBES REMOVED (DAYS)	LENGTH OF DISEASE (YEARS)
	HRS.	MIN.							
W. W. No. 11	2	48	Pressure ↓ 10 points Pulse ↑ 10 points After 2 hours	1,320	2,500	0	1,500	2	2
M. F. No. 21	2	25	Pressure ↓ 20 points Pulse ↑ 10 points After 1 hr., 45 min.	1,148	2,000	500	1,400	2	4
I. H. No. 3	2	20	Pressure ↓ 40 points Pulse stabilized from beginning of procedure	1,145	2,000	0	0	1	3
J. M. No. 14	2	14	Pressure ↓ 5 points Pulse ↑ 10 points After 1 hr., 45 min.	1,058	2,500	0	1,950	2	3
P. W. No. 22	1	50	Pressure ↓ 10 points Pulse ↑ 10 points After 1 hr., 10 min.	760	2,000	1,000	2,000	3	4
B. B. No. 12	2	30	Pressure ↓ 10 points Pulse ↑ 20 points After 1 hr., 45 min.	1,173	2,500	0	650	1	1½
L. B. No. 10	2	10	Pressure ↓ 15 points Pulse ↑ 10 points After 1 hr., 25 min.	860	2,500	0	600	2	1½
L. A. No. 33	2	25	Pressure ↓ 15 points Pulse ↑ 10 points After 1 hr., 55 min.	1,865	3,000	500	?	1	3

E. R. C. No. 30	2	36	Pressure ↓ 20 points Pulse ↑ 10 points From start of operation	1,615	2,500	1,500	800	2	7
R. M. No. 18	2	15	Pressure ↓ 20 points Pulse ↑ 10 points After 1 hr., 35 min.	680	2,000	500	1,350	2	5
A. L. B. No. 16	3	5	Pressure ↓ 20 points Pulse ↑ 20 points After 2 hrs., 30 min.	1,810	3,000	0	825	1	1½
L. R. No. 19	2	37	Pressure ↓ 20 points Pulse ↑ 20 points After 1 hr., 50 min.	1,452	2,500	0	900	2	2
H. S. No. 20	3	0	Pressure ↓ 20 points Pulse ↑ 20 points After 2 hrs., 15 min.	1,814	3,000	3,300	3,115	3	2
M. D. No. 28	2	10	Pressure ↓ 15 points Pulse ↑ 5 points After 1 hr., 35 min.	960	2,000	500	750	1	7
R. L. S. No. 27	3	0	Pressure ↓ 20 points Pulse ↑ 20 points After 2 hrs., 20 min.	3,353	5,500	2,500	935	3	10
S. L. No. 26	2	15	No change	760	2,500	1,500	1,100	2	3
J. A. J. No. 34	2	0	Pressure ↓ 20 points Pulse ↑ 10 points After 1 hr., 30 min.	593	2,000	0	800	1	3
Average of 17 patients	2	27	Pressure ↓ 13 points Pulse ↑ 11 points	1,310	2,588	690	1,242	2	3.7

TABLE VI. CASES WITHOUT CONCOMITANT THORACOPLASTY

NAME AND CASE NUMBER	ANESTHESIA TIME HRS.	ANESTHESIA TIME MIN.	ALTERATION OF BLOOD PRESSURE AND PULSE DURING OPERATION	BLOOD LOSS DURING OPERATION (C.C.)	BLOOD GIVEN DURING OPERATION (C.C.)	SUBSEQUENT BLOOD GIVEN (C.C.)	BLOOD LOSS IN DRAINAGE BOTTLE (C.C.)	TUBES REMOVED (DAYS)	LENGTH DISEASE (YEARS)
E. B. No. 9	2	10	No change	1,366	2,500	500	1,450	2	9
A. T. No. 5	2	30	Pressure ↓ 20 points Pulse ↑ 5 points After 2 hrs.	1,271	2,000	500	900	1	3½
M. H. T. No. 4	2	25	Pressure ↓ 25 points Pulse ↑ 10 points After 2 hrs.	1,603	2,500	0	500	2	7
H. B. No. 13	2	10	Pressure ↓ 40 points Pulse ↑ 20 points From beginning of operation	1,715	3,000	1,000	1,475	2	2½
M. Y. No. 8	2	10	Pressure ↓ 30 points Pulse ↑ 20 points From beginning of operation	729	2,000	0	600	2	1
T. W. No. 29	2	6	Pressure ↓ 20 points Pulse ↑ 20 points After 1 hr., 25 min.	812	2,000	?	?	?	5
K. S. No. 17	1	40	Pressure ↓ 10 points Pulse stable Throughout procedure	606	2,000	1,000	None recorded	2	4
B. D. No. 31	3	0	Pressure ↓ 20 points Pulse ↑ 20 points After 2 hrs., 30 min.	2,450	3,500	500	2,700	3	4
J. C. No. 7	2	30	Pressure ↓ 20 points Pulse ↑ 20 points After 1 hr., 45 min.	1,785	3,500	0	775	3	2

B. B. No. 6	3	10	Pressure ↓ 30 points Pulse stable After 1 hr., 30 min.	3,635	6,000	500	900	1	8
E. H. No. 32	1	50	No significant continuous drop	1,908	3,500	1,000	1,500	2	6
E. M. C. No. 1	2	0	No change	858	1,500	Not recorded	Not recorded	2	1
H. B. No. 15	3	0	No change	1,650	3,000	500	850	1	2
C. C. No. 2	2	30	Pressure ↓ 30 points Pulse ↑ 10 points After 1 hr., 45 min.	1,351	2,500	500	800	1	2
B. J. No. 25	2	15	Pressure ↓ 10 points Pulse ↑ 5 points After 1 hr., 45 min.	1,551	3,000	0	975	2	3
R. D. No. 23	2	30	No change	1,185	2,500	0	625	1	6½
S. C. No. 24	2	0	Pressure ↓ No change Pulse ↑ 30 points After 1 hr.	990	2,500	0	500	1	7
Average 13 patients 4 patients	1 2	8 24 >	Pressure ↓ 14 points Pulse ↑ 8 points	1,498	2,790	409	1,039	2	4.4

TABLE VII

	ANESTHESIA TIME		ALTERATION OF BLOOD PRESSURE AND PULSE DURING OPERATION	BLOOD LOSS DURING OPERATION (C.C.)	BLOOD GIVEN DURING OPERATION (C.C.)	SUBSEQUENT BLOOD GIVEN (C.C.)	BLOOD LOSS IN DRAINAGE BOTTLE (C.C.)	TUBES REMOVED (DAYS)
	HRS.	MIN.						
Combined procedure	27	2	Pressure ↓ 15 points Pulse ↑ 10 points	1,310	2,588	690	1,240	1.8
Separate procedure	24	2	Pressure ↓ 14 points Pulse ↑ 8 points	1,500	2,790	500	1,110	2.0

the decostalized chest wall, allowing the shoulder blade structures to fall in, affords a much more solid support to the mediastinum than would a compressible cushion of air in an empty pleural space, as in the case of primary pneumonectomy. This support is reinforced further by a tight pressure dressing to eliminate any paradoxical motion in that region. Allowing for the fact that there is no total obliteration of pleural space by the described thoracoplasty, it is believed that the thin layer of coagulum in the residual space still provides a less compressible background. In all the 12 to 24 hour postoperative chest films in this series, the pneumonectomized "lung field" shows total opacity with no air pocketing in spite of the drainage tube. We believe that this firm support to the mediastinal structures prevents any dangerous degree of swinging and displacement. We also have never found it necessary to readjust the intrapleural pressure for correction. In fact, we feel that it is this more stabilized mediastinum that improves the efficacy of the cough mechanism, as less of its expulsive force is dissipated through a swing of the mediastinal structures. This more stabilized mediastinum and a pleural space that is greatly reduced by the concomitant thoracoplasty are believed to allow adequate underwater drainage without the danger of overdecompression and shifting of the mediastinum to a dangerous degree, as in the case of primary pneumonectomy.

It would seem, therefore, in the patients with concomitant pneumonectomy and thoracoplasty that there is no specific problem in the immediate postoperative period except for the blood replacement. We are impressed by the relatively benign postoperative course of these patients in the critical postoperative period. It is, therefore, our feeling that this concomitant thoracoplasty improves or reduces the postoperative morbidity rather than otherwise.

DISCUSSION

It is not the intention of this paper to recommend pneumonectomy with concomitant thoracoplasty as a procedure to be applied to all routine cases of tuberculosis which require total lung resection. However, it is the purpose of this article, on a comparative study of 17 cases of combined procedure and 17 comparable cases without combined procedure, to re-evaluate the degree of selectivity for application of this concomitant procedure. Our experience seems to corroborate the statement made by Iverson that the procedure does not materially increase the operative time, blood loss, or over-all morbidity. The efficacy of cough in the postoperative period is impressively enhanced over that following primary pneumonectomy. The "freedom" of concern about mediastinal swing and displacement is also a striking feature in the immediate postoperative period. As to the effect of thoracoplasty on the breathing capacity of the remaining lung, we have not come across any patient who suffers from increasing impairment. In patients who have a longer period of follow-up, there was no evidence of scoliosis (Fig. 5) and, thus, no decrease of ventilatory effort with the passage of time is anticipated. This is primarily attributable to the preservation of relatively long anterior stumps of ribs and

the transverse processes. In cases of a potentially infected pleural space, as in the patient who had a Monaldi tract, we were particularly gratified by the lack of empyema formation, a result, made possible, at least partially, by the safe and adequate drainage of the residual pleural space with the concomitant thoracoplasty. As stated, such space could be drained until all oozing and weeping had ceased, carrying with it most of the infected organisms, without the danger of overdecompression with shifting of mediastinum, as in case of primary pneumonectomy. In addition, the findings from the analysis of the group with combined procedure indicated that the operative and postoperative morbidity and mortality compares favorably, not only with the patients who had the separate procedure, but with other series of primary pneumonectomy as well. Samson,[27] in 1951, mentioned 15 cases of pneumonectomy and concomitant thoracoplasty "with no immediate postoperative complication of major concern." It is, therefore, felt that possibly the selectivity of this combined

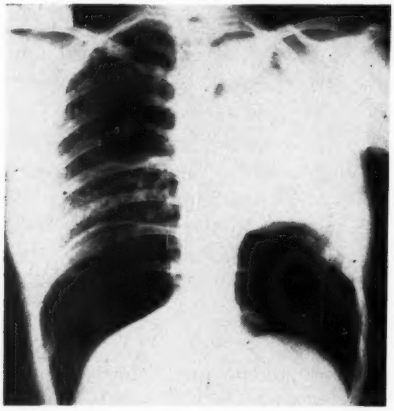

Fig. 4.

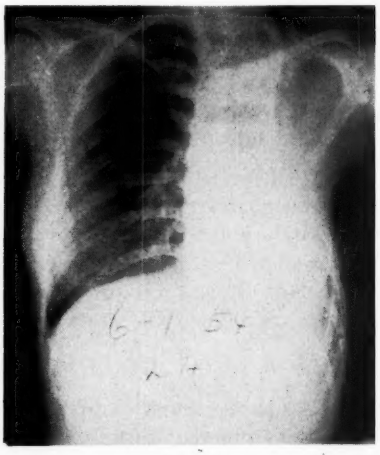

Fig. 5.

Fig. 4.—Case No. 33. L. A., a 23-year-old white woman, was admitted March 2, 1950, far advanced, C. She received various combinations of streptomycin, INAH, and PAS, and pneumoperitoneum for three years. A combined procedure was performed on July 29, 1953, with uneventful recovery. Sputum was positive for the last time on Nov. 3, 1952, and has remained negative since. Specimen shows destroyed lung with bronchiectasis, endobronchitis, and active tuberculosis granulation tissue. She was discharged home June 24, 1954.

Fig. 5.—Case No. 33. L. A., same patient. Film taken prior to discharge June 24, 1954, 11 months postoperatively. It shows the lack of gross scoliosis.

pneumonectomy and thoracoplasty should be less than formerly believed to be necessary. It is also felt that the notoriety given the combined procedure in the literature, as being a very risky operation, accompanied with high morbidity if not mortality, is not fully justified. It is unfortunate that a distinction has not always been made between operative morbidity and mortality of the combined procedure of pneumonectomy and thoracoplasty and that of lobectomy and concomitant thoracoplasty. The lung tissue in a freshly decostalized pleural cavity is more likely to be involved in complications such as atelectasis, poor re-expansion of lung, hemothorax, infection of pleural space, etc. This is

due to the ineffectual coughing mechanism, in the presence of a flail chest wall, to evacuate secretions in the ipsilateral lung tissue. In combined lobectomy and thoracoplasty, when usually no more than a five-rib thoracoplasty is performed, the subscapular space is not obliterated by the falling in of the shoulder blade structure and thus the paradoxical motion of the decostalized chest wall persists under the scapula. Stead[28] has demonstrated the undesirable features of such combined procedure very convincingly in his physiologic studies. In the case of pneumonectomy, where there is no lung tissue left in the pleural space with a flail and decostalized chest wall, the danger of such complication, therefore, does not exist.

In view of our experience with this combined procedure of pneumonectomy and thoracoplasty, we would like not only to corroborate the feelings of Iverson and Samson, but also to hope for wider application of this procedure. It is felt that, except in cases with serious contraindication, such as in the extreme of life, severe degenerative diseases, or blood transfusion reaction, etc., consideration of this procedure in appropriate cases should be seriously entertained. As to its usefulness in pneumonectomy for diseases other than tuberculosis, reevaluation should also be made with renewed interest. Since Evarts Graham did the first successful pneumonectomy and concomitant thoracoplasty for bronchogenic carcinoma of the lung, this procedure has not been given the proper amount of evaluation and consideration to have it stigmatized as too radical an operation. It is felt that this procedure should be of help in the problem of the remaining space until such time, however remote, when the present difficulty in prosthesis will be resolved. The fact that tuberculous patients are conceded to be more likely to have a contracted blood volume, subnormal liver function, and be generally weaker than a person who has only short-term disease, such as carcinoma or lung abscess, one cannot help but wonder whether the satisfactory results in this series, however small it is, could not be duplicated, if not bettered, in nontuberculous patients. At least this procedure deserves the consideration of a surgeon who might find occasion to employ it.

CONCLUSION

A comparative study has been made of 17 cases of combined pneumonectomy and thoracoplasty and 17 cases of separate procedure, done consecutively over a period of 21 months. The two groups were compared first and found to have essentially similar composition as regards to race, sex, age groups, extent of disease, activity of lesions ascertained from resected specimen, length of disease, and length of preoperative antituberculosis drug therapy. It was found that from these two comparable groups, the final results as to sputum conversion, arrest of disease, discharge status, and mortality rate, are closely akin and also compare favorably with other series of primary pneumonectomy. It was also found that the operative and immediate postoperative morbidity rate were not as high as reputed to be, nor out of order when compared with that of other series. In fact, the increase in efficacy of cough mechanism and general lack of complications secondary to mediastinal displacement in the immediate postoperative period are especially impressive. It is, therefore, felt not unwarranted that

the highly selective use of this concomitant pneumonectomy and thoracoplasty should be re-evaluated as to its range of applicability, not only in tuberculous patients, but in nontuberculous patients as well.

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EXPERIMENTAL INTERATRIAL SEPTAL DEFECT: HEMODYNAMIC AND ELECTROCARDIOGRAPHIC STUDIES AT NORMAL TEMPERATURE AND DURING ARTIFICIAL HIBERNATION

VIRGILIO A. DE CARVALHO PINTO, M.D.*
SÃO PAULO, BRAZIL

THE surgical repair of the interatrial septal defect (IASD), a fairly common malformation, has been carried out successfully in recent years. Such successful clinical results have been largely due to experimental studies. Lack of data on several features related to IASD, such as the hemodynamic and electrocardiographic changes derived from the creation and closure of the defect, has led us to the present investigation. This paper is a report of our experience with the physiologic and surgical aspects of the creation and closure of the IASD in the dog, under different conditions.

Creation and closure of a IASD, in the same operative sitting, under normal temperature conditions and during artificial hibernation, were carried out in 50 animals. The results obtained under strictly homogeneous conditions were submitted to statistical analysis.

MATERIAL AND METHODS

Healthy, adult, male mongrel dogs, weighing 15 to 18 Kg., were divided into two groups. (1) Twenty animals were operated on under normal temperature conditions; (2) thirty animals were operated on during artificial hibernation (hypothermia obtained by pharmacologic means plus refrigeration—Laborit). In both groups, the blood flow was temporarily occluded (40 to 50 seconds) and the IASD created under direct vision. Closure of the defect in Group I was carried out according to the technique used by Gross (1952) and, in Group II, under direct vision and interruption of blood flow (6 minutes).

Intracardiac pressure curves in the left and right atria and right ventricle as well as electrocardiographic tracings in the classic, unipolar limb and direct epicardial leads were recorded in all animals, before creation of the defect, while it was open, and after its closure. In Group II, electrocardiograms were also taken before opening the chest and after surgical repair, with closed chest and return to initial temperature after rewarming.

Anesthesia in Group I.—Operations were performed under intravenously administered Nembutal anesthesia (0.33 gram per Kg. of body weight).

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*Assistant Professor at the Department of Surgery and Experimental Surgery of the Medical School of the University of São Paulo (Director: Prof. E.da Silva Bastos).

Anesthesia and Hibernation in Group II.—Intramuscular Amplictil and Phenergan (Rhodia), 0.8 mg. per Kg. of body weight was used, followed by slow intravenous administration of Amplictil and Phenergan forty-five minutes later (0.8 mg. per Kg. of body weight), dissolved in 20 c.c. of saline solution. Slow, intravenous administration of Pentothal sodium (2.5 per cent), 0.003 gram per Kg. of body weight. Endotracheal intubation. The animal was immersed in water containing ice cubes, until rectal temperature dropped to 29° C., which occurred after 20 to 30 minutes. Artificial respiration was maintained with Takaoka's apparatus connected to an oxygen pump. There was intravenous administration of procaine 4 per thousand, plus Amplictil and Phenergan throughout the procedure.

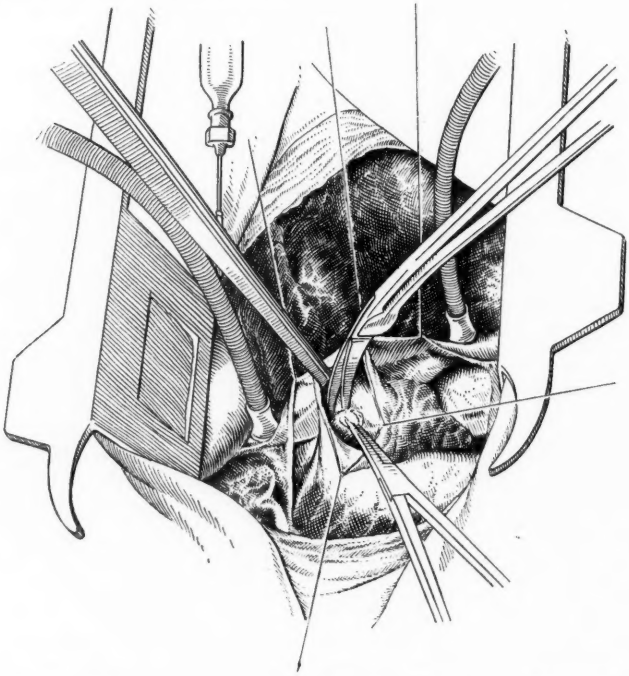

Fig. 1.—Interruption of the venae cavae. Satinsky's clamp withdrawn. Removal of interatrial septum.

After surgery, rewarming was accomplished by placing the animal in a bath at 40° C., until temperature returned to normal level (approximately three hours).

SURGICAL PROCEDURES

Incision was through the fourth right interspace. Five cubic centimeters of 1 per cent procaine was injected into the pericardium. The pericardium was widely opened ventrally to the phrenic nerve and retracted by three sutures. Dissection and ligature of the azygos vein were carried out. The superior and

inferior venae cavae were dissected and mobilized. Cotton thread sutures (No. 3-0) were placed around them. Two retraction silk sutures were placed on the atrial wall and a Satinsky clamp was placed on the same. The mean temperature of dogs submitted to hibernation was 27.5° C.

Creation of IASD Under Direct Vision.—Interruption of blood flow in the superior and inferior venae cavae (Fig. 1). Section and removal of the greater part of the septum, creating a large defect through which the index finger could be introduced with ease, 1.5 cm. in diameter (Fig. 2). Circulation was restored after 40 to 50 seconds of interruption. The atrial wall was closed with a running suture of No. 3-0 silk. The mean temperature of hibernated dogs was 26.3° C.

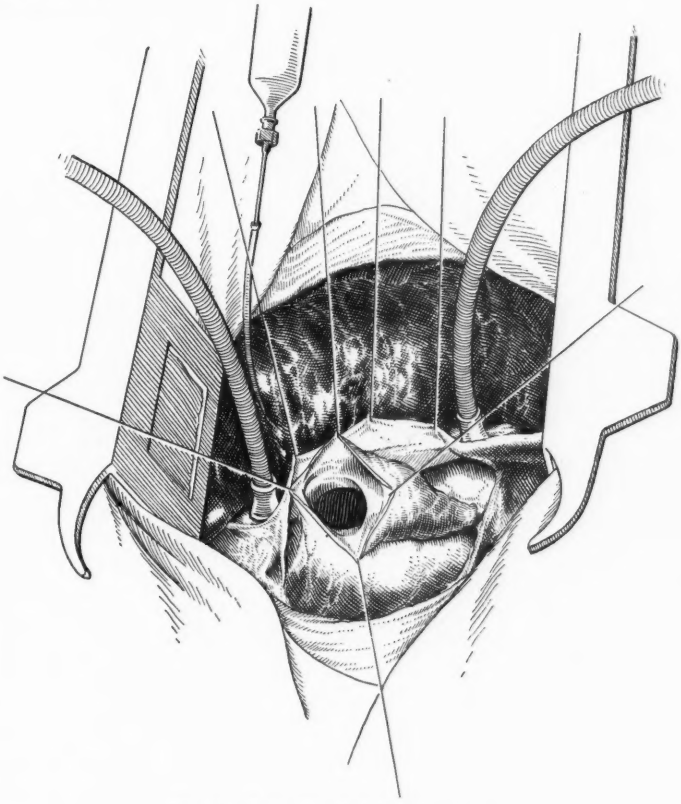

Fig. 2.—Defect created in the septum.

Closure of IASD.—Group I. The septal defect was closed according to Gross (Fig. 3) in the animals operated on at normal temperature. The atrium remained open from 6 to 8 minutes.

Group II. The septal defect was closed under direct vision in the hibernated dogs. After reopening the original atrial incision, occlusion of both

Fig. 3.—Closure of interatrial septal defect, according to Gross; first stitch.

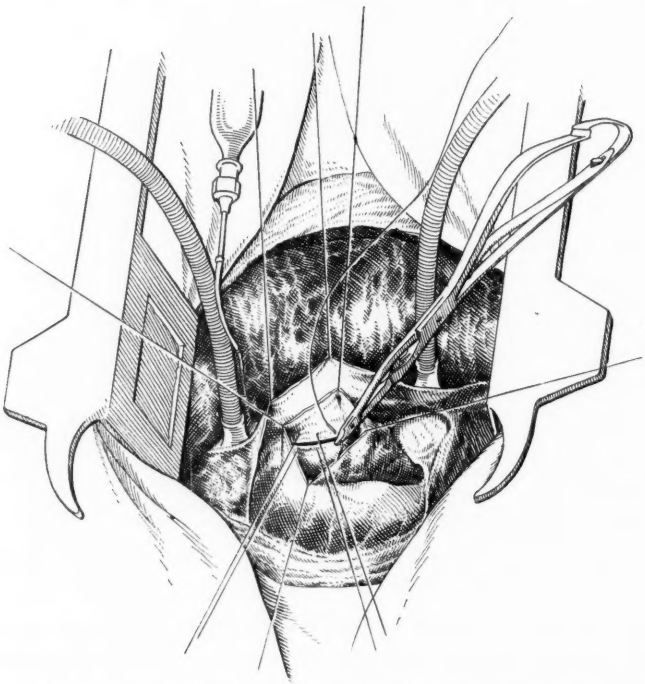

Fig. 4.—Closure of interatrial septal defect under direct vision.

venae cavae, pulmonary artery and aorta up to the origin of the coronary arteries (Figs. 4 and 5). The septal defect was closed under direct vision, with Atraumatic needle, No. 3-0 silk, by three stitches. Cardiac and thoracic cavities were flooded with saline solution. Suture of atrial wall with separated stitches, after restoration of circulation. There was interruption of circulation in the venae cavae for 6 minutes (1.5 for suture of defect). The mean temperature of the hibernated dogs was 25.7° C.

Standard closure of the chest. The animals were sacrificed the day following the operation.

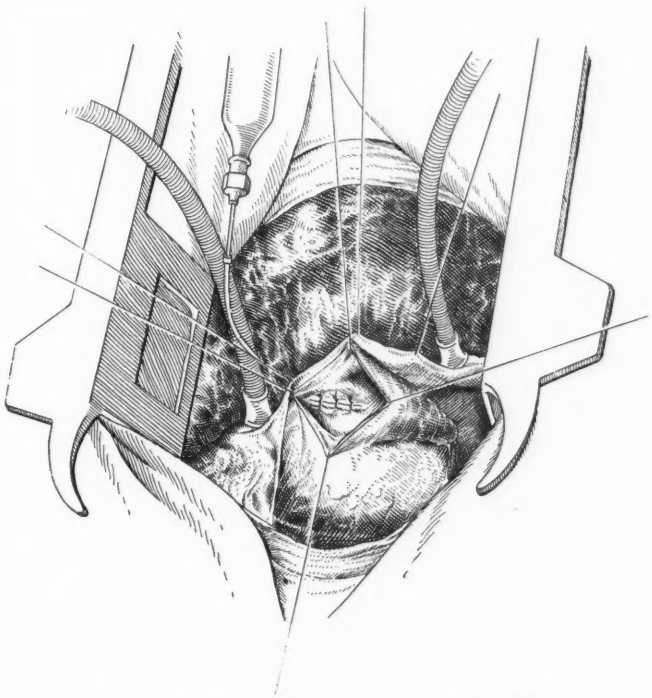

Fig. 5.—Complete closure of interatrial septal defect.

RECORDS OF INTRACARDIAC PRESSURES

Pressures in right and left atria and right ventricle were recorded by means of the Sanborn electromanometer, model 121-A, during the three surgical stages; prior to creation of IASD, when it was open, and after its closure.

For the atrial pressure measurement, the average and instantaneous pressures were considered. The former was obtained by planimetric integration and the latter at the extreme values of the following waves (Fig. 6):

Wave A—positive wave, corresponding to the elevation of the intra-atrial pressure, determined by the contraction of atrial walls.

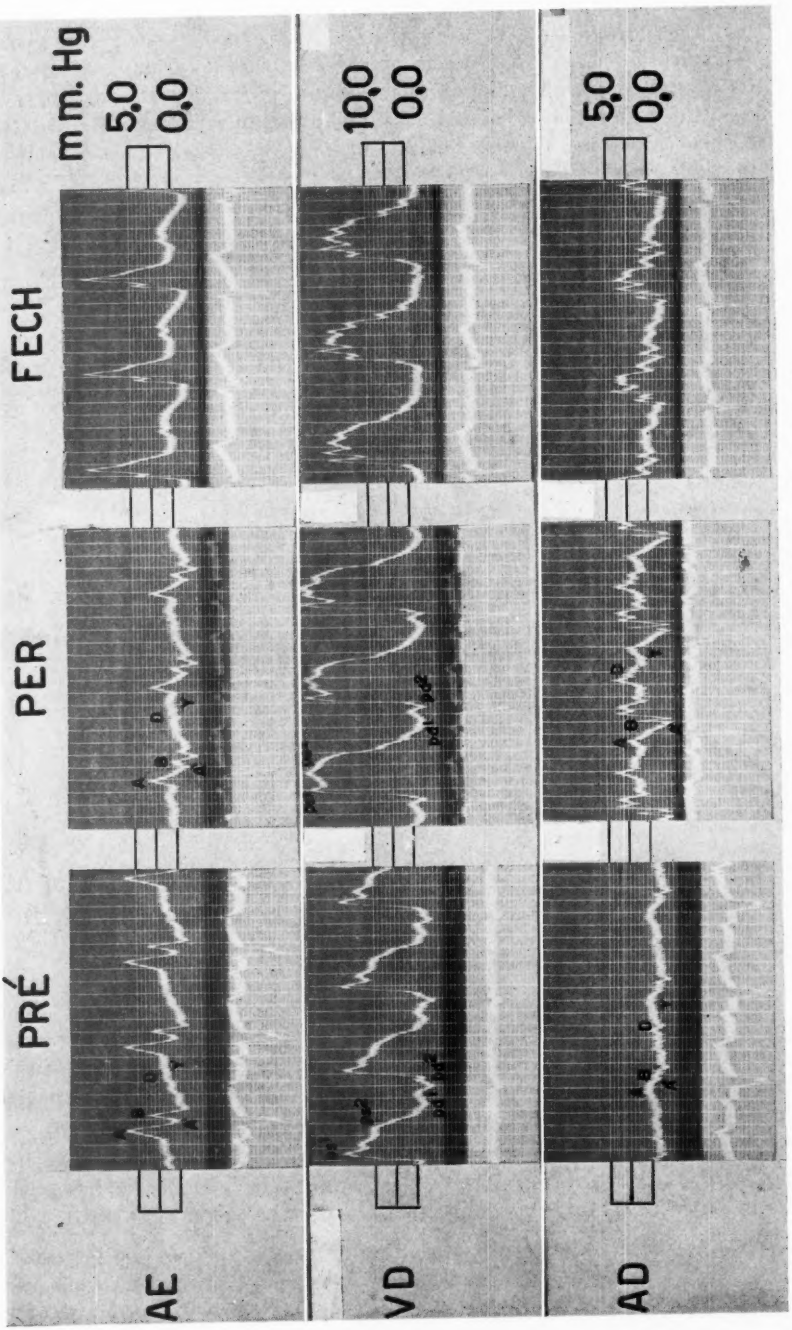

Fig. 6.— Records of intracardiac pressures of Observation No. 30.

Wave B—positive wave, determined by the increase of intra-atrial pressure at the moment in which the atrioventricular valves are closed.

Wave D—positive wave which expresses atrial filling, during the period at which the atrioventricular valves are closed.

Wave A′—negative wave corresponding to the end of the atrial systole.

Wave Y—negative wave which follows the D wave and precedes the A wave; expresses the degrees of atrial emptying, after opening the atrioventricular valves.

For the ventricular pressure measurement, the average and instantaneous pressures were taken into consideration. The first was obtained by planimetric integration and the latter at the extreme values of the following waves:

Ps_1—positive wave of the ventricular curve, corresponding approximately to the end of the isometric contraction.

Ps_2—positive wave following a negative deflexion after Ps_1.

Pd_1—negative wave after the isometric relaxation.

Pd_2—negative wave at the end of the ventricular systole.

The nomenclature used was suggested by Borges (1953, 1954, 1955), based on the studies of Wenckebach and Winterberg (1927) for the atrial pressures and on the nomenclature adopted by the Laboratory of Hemodynamics of the National Institute of Cardiology of Mexico for the ventricular pressures.

ELECTROCARDIOGRAPHIC STUDY

Electrocardiographic tracings were recorded by means of the Viso-Cardiette Sanborn apparatus, model 52, under the usual conditions of film speed and amplitude padronization. Classic leads (D_1, D_2, D_3), unipolar limb leads of Goldberger (aVR, aVL, aVF), and direct epicardial leads were taken with the animal in the same position (left lateral decubitus).

Sequence of tracings:

a. *Animals operated on at normal temperature:* Classic and unipolar limb leads of the anesthetized animal, after opening of the chest; epicardial leads before creation of IASD; epicardial leads after creation of the IASD; classic and unipolar limb leads after creation of IASD; epicardial leads after closure of IASD; classic and unipolar limb leads after closure of IASD, with open chest.

b. *Animals operated on under artificial hibernation:* Classic and unipolar limb leads of the animal at normal temperature; classic and unipolar limb leads of the hypothermic animal, after opening the chest; epicardial leads before creation of IASD; epicardial leads after creation of IASD; classic and unipolar limb leads after creation of IASD; epicardial leads after closure of IASD; classic and unipolar limb leads after closure of IASD; classic and unipolar limb leads after rewarming to normal temperature.

The direct epicardial leads were taken according to Barbato (1952). Tracings were studied according to classic rules of electrocardiography and, of

each observation, the following items were analyzed: rhythm, frequency, P wave (duration, amplitude, P angle, slurring and notch), P-R interval, QRS complex (duration, amplitude, QRS angle, slurring and notch), electrocardiographic position of the heart, Q-T interval and R/S relation of direct ventricular epicardial tracings.

To remove the influence of frequency on the P-wave duration values, P-R interval, duration of the QRS complex and on the Q-T interval, P_c, $P\text{-}R_c$, QRS_c and $Q\text{-}T_c$ were studied, respectively, according to the following formulas:

P_c, that is, the duration of the "corrected" P wave, according to the formula $P\text{-}P_c = (R\text{-}R)^{0.12196}$ modified from Fujiwara (1939). Before using it, a statistical test was made.* This demonstrated its adaptability to our cases.

$P\text{-}R_c$, that is, the "corrected" P-R interval, obtained by the same formula used for P, also adaptable to our data.

QRS_c, that is, the duration of the "corrected" QRS complex, calculated according to the formula $QRS = QRS_c$ R-R suggested by the formula used for man (Albers and Bedbuhr, 1941), and which was adaptable to our material.

$Q\text{-}T_c$, that is, the "corrected" Q-T interval, calculated by the formula of Bazett, $Q\text{-}T = Q\text{-}T_c$ R-R, and which was adaptable to our cases.

The QRS amplitude was studied, taking into consideration the electrocardiographic position of the heart, and determined according to Sodi-Pallares (1951).

The changes of the RS-T segment are presented only in the hibernated group, as the changes found in the series of animals operated upon at normal temperature do not differ from those commonly found with the simple exposure of the heart to air and room temperature.

The data obtained in the hemodynamic and electrocardiographic records are presented with the following abbreviations which designate the time at which they were performed:

PRÉ—before creation of IASD
PER—after creation of IASD
FECH—after closure of IASD

In the hibernation group:

NM—prior to artificial hibernation.
AQ—after rewarming.

The changes observed in the several experimental phases are expressed by the differences between the corresponding values and percentage variations, in the following way:

PRÉ-NM—changes produced by hibernation to the values of normal temperature.
PER-PRÉ—changes caused by the production of IASD to the values observed before the creation of the defect.

*From the equation $y = k\,x^c$, where $y = P$ and $x = R\text{-}R$, the hypothesis of $c = 0.122$ was tested, calculating

$$F = \frac{(N-2)\,[N\Sigma(\log x)\,(\log y) - (\Sigma\log x)\,(\Sigma\log y) - c[N\Sigma(\log x)^2 - (\Sigma\log x)^2]\,]^2}{[N\Sigma(\log y)^2 - (\Sigma\log y)^2]\,[N\Sigma(\log x)^2 - (\Sigma\log x)^2] - [N\Sigma\log x \log y - (\Sigma\log x)\,(\Sigma\log y)]^2}$$

in which F has the distribution F of Snedecor for 1 and N-2 degrees of liberty.

FECH-PER—changes caused by the closure of the IASD to the values observed while it was open.

FECH-PRÉ—relations between values observed after closure and those prior to creation of IASD.

AQ-FECH—modifications produced by rewarming to the values observed after closure of IASD.

AQ-NM—relations between values observed after rewarming and those of normal temperature.

The percentage variations were obtained by the following relations: PRÉ-NM/|NM|; PER-PRÉ/|PRÉ|; FECH-PER/|PER|; FECH-PRÉ/|PRÉ|; AQ-NM/|NM|. The denominator represents the absolute value.

The several items studied, concerning hemodynamic and electrocardiographic findings, are presented in tables and analyzed according to their maximal and minimal values and arithmetic mean, standard deviation, test of mean difference and distribution of cases, according to one of the three following conditions: positive difference (increased); negative difference (decreased); null difference (unaltered).

Percentage variations were used and, the increase or decrease of the values above 10 per cent or below—10 per cent, respectively, was considered.

RESULTS

The results refer to data obtained only under sinusal rhythm:

1. Intracardiac pressures of dogs operated on under normal temperature conditions (Table I, Fig. 7).

2. Intracardiac pressures of dogs operated on during artificial hibernation (Table II, Fig. 8).

3. Electrocardiographic tracings of dogs operated on under normal temperature conditions (Table III, Fig. 9).

4. Electrocardiographic tracings of dogs operated on during artificial hibernation (Table IV, Fig. 10).

DISCUSSION

Several investigators have reported different techniques for the production of the interatrial septal defect, some by blind techniques, others under direct vision, or with the aid of special instruments. The production of IASD brought us the first technical problems. As the defect should be relatively large, the greater part of the septum had to be removed. It appeared desirable, therefore, to create the lesion under direct vision, according to Swan and co-workers (1950). Standardization of the operative procedure enabled us to create the defect in a relatively short time (40 to 50 seconds), with good results.

After recording the intracardiac pressures and the electrocardiographic tracings during the presence of the IASD, closure was performed.

The experimental approach to direct vision surgery of the heart is being studied at the present time by several authors, with the use of extracorporeal circulation, hypothermia, and extracorporeal circulation associated with hypothermia.

TABLE I. SYNTHESIS OF THE RESULTS OF INTRACARDIAC PRESSURES OF THE CASES UNDER SINUSAL RHYTHM
(Animals operated on at normal temperature, mm. Hg)

		AE						AD						VD				
		MEAN PRESSURE	A	B	D	A′	Y	MEAN PRESSURE	A	B	D	A′	Y	MEAN PRESSURE	Ps_1	Ps_2	Pd_1	Pd_2
PRÉ	Number of cases	20	20	19	20	20	20	20	18	16	19	19	18	20	20	20	20	20
	Values mx	1.4	4.0	2.0	2.5	1.5	3.0	1.2	3.5	3.5	1.5	1.0	1.5	17.4	53.5	45.0	1.0	2.5
	Values mn	−1.5	−2.0	−1.5	−0.5	−3.0	−3.0	−2.0	−1.0	−1.5	−1.5	−3.0	−2.5	3.9	18.5	15.0	−6.0	−6.0
	Arithmetic mean	0.23	1.15	0.68	1.25	−0.85	−0.20	−0.29	0.94	0.44	−0.10	−0.95	−0.44	8.61	34.52	26.57	−1.87	−1.00
	Standard deviation	0.811	1.424	0.988	0.966	1.101	1.568	0.743	1.211	1.237	0.774	0.956	0.953	3.962	11.003	8.524	2.120	1.926
PER	Number of cases	19	19	19	19	18	19	18	18	17	18	17	17	18	18	18	18	18
	Values mx	2.6	2.5	3.5	3.0	2.0	2.5	2.0	5.0	3.5	2.0	0.5	2.5	18.6	64.0	55.0	2.5	2.0
	Values mn	−0.5	−0.5	0.0	−0.5	−1.5	−2.0	−1.2	−1.0	−1.0	−1.0	−3.0	−1.5	5.8	22.0	16.0	−5.0	−2.0
	Arithmetic mean	0.40	0.87	1.13	1.13	−0.36	−0.29	−0.09	0.69	0.68	0.44	−1.06	−0.38	11.76	41.05	33.47	−0.72	0.11
	Standard deviation	0.751	0.779	0.796	0.895	0.801	1.170	0.721	1.351	1.131	0.662	1.072	0.976	3.821	11.955	11.612	2.102	1.231
FECH	Number of cases	15	15	14	15	15	15	16	15	15	16	15	15	15	15	15	15	15
	Values mx	8.7	15.0	8.0	9.5	7.0	9.0	1.0	5.5	5.0	1.5	0.5	2.0	16.3	55.0	46.0	2.5	2.5
	Values mn	−0.3	−0.5	0.0	0.0	−6.5	−1.5	−1.0	−0.5	−0.5	0.0	−2.5	−1.5	5.6	10.0	16.0	−3.5	−2.0
	Arithmetic mean	2.52	3.67	3.36	3.37	0.87	2.00	0.19	1.00	1.17	0.75	−0.80	−0.07	8.56	28.77	27.63	−0.23	0.27
	Standard deviation	2.787	4.443	2.560	2.545	3.512	3.185	0.558	1.669	1.305	0.632	0.751	0.883	2.970	12.159	8.123	1.699	1.294

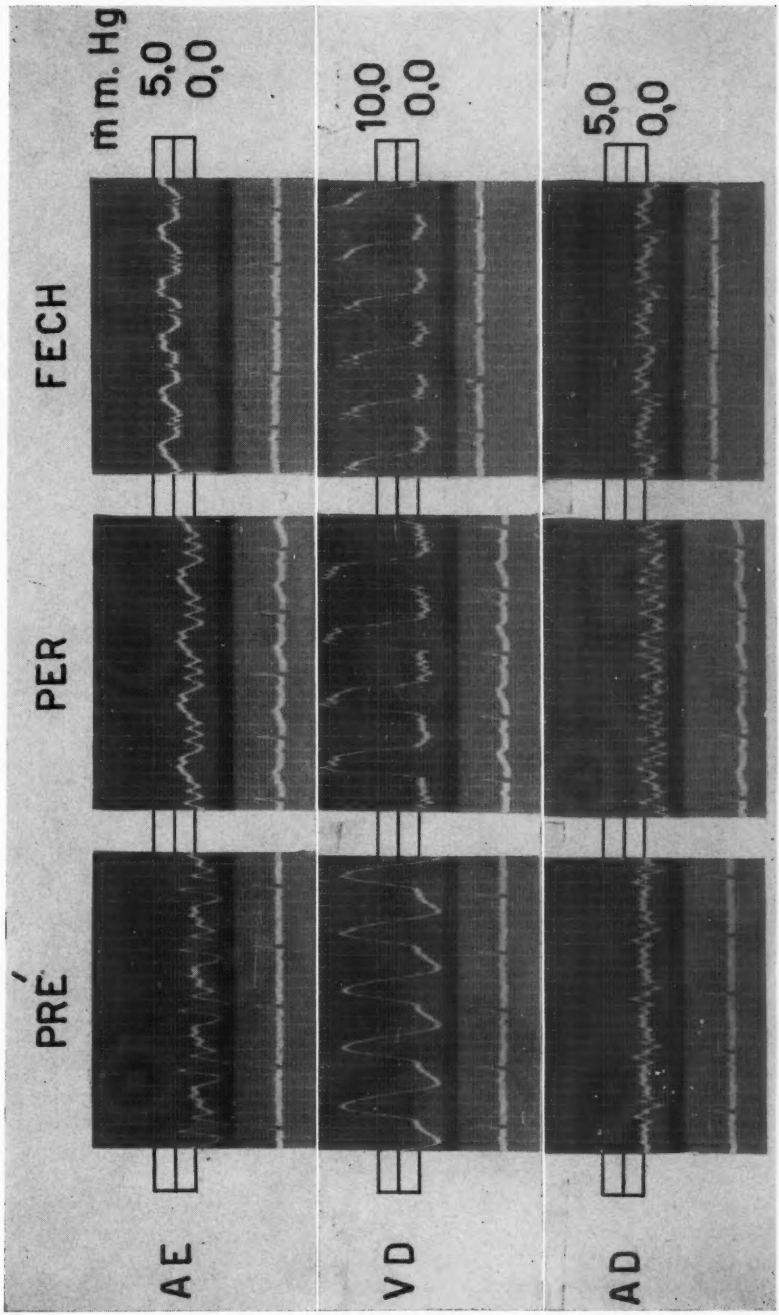

Fig. 7.—Records of intracardiac pressures of Observation No. 7.

TABLE II. SYNTHESIS OF THE RESULTS OF INTRACARDIAC PRESSURES OF CASES UNDER SINUSAL RHYTHM
(Animals operated on under artificial hibernation, mm. Hg)

		AE						AD						VD				
		MEAN PRESSURE	A	B	D	A′	Y	MEAN PRESSURE	A	B	D	A′	Y	MEAN PRESSURE	Ps_1	Ps_2	Pd_1	Pd_2
PRÉ	Number of cases	28	28	28	28	28	28	29	29	27	29	27	28	29	26	27	27	29
	Values mx	4.5	10.5	8.5	5.0	6.5	5.5	2.9	8.5	8.5	3.5	2.5	3.5	9.6	27.0	26.0	2.0	2.0
	Values mn	−1.2	−1.5	0.0	−1.0	−2.0	−2.5	−1.9	−1.5	−1.0	−2.0	−3.5	−2.5	3.0	8.0	7.0	−2.0	−2.0
	Arithmetic mean	1.04	3.30	3.25	1.39	0.96	0.82	−0.02	1.59	1.18	−0.34	−0.55	−0.39	5.01	14.71	14.05	−0.52	−0.45
	Standard deviation	1.392	2.286	2.401	1.383	2.211	1.743	1.135	2.036	2.010	1.302	4.479	1.343	1.658	4.384	5.148	1.051	1.012
PER	Number of cases	27	25	27	27	25	25	24	24	24	24	23	24	24	23	25	22	24
	Values mx	3.1	6.0	6.5	4.0	4.0	3.0	2.8	3.5	5.0	3.0	2.5	2.5	15.1	42.5	37.5	1.0	2.5
	Values mn	−1.5	−1.0	−1.0	−1.0	−2.5	−3.0	−1.4	−2.0	−1.5	−1.0	−2.5	−2.0	2.3	10.0	9.0	−4.0	−3.5
	Arithmetic mean	0.41	1.38	1.87	0.91	0.18	−0.10	0.10	1.12	1.60	0.52	−0.33	−0.35	6.94	18.69	17.88	0.27	0.02
	Standard deviation	1.040	1.657	1.790	1.225	1.523	1.283	2.220	1.279	1.525	1.047	1.230	0.983	2.761	8.563	6.850	1.120	1.229
FECH	Number of cases	12	12	12	12	12	12	9	8	8	9	6	7	10	10	11	10	11
	Values mx	2.0	3.0	5.0	4.0	2.0	2.0	1.4	3.5	5.0	1.5	1.5	1.0	9.5	26.0	21.5	2.0	2.5
	Values mn	−0.3	0.0	1.5	0.0	0.0	−1.0	−1.5	−1.0	−1.5	−1.5	−2.0	−1.5	3.9	10.0	8.5	−1.0	−2.0
	Arithmetic mean	0.75	1.54	3.00	1.71	0.67	0.21	−0.11	0.87	1.06	0.11	−0.83	−0.43	5.63	16.05	16.23	0.15	−0.45
	Standard deviation	0.762	1.033	1.348	1.322	0.807	0.916	0.931	1.529	2.078	1.083	1.505	1.159	3.339	5.036	4.502	1.180	1.213

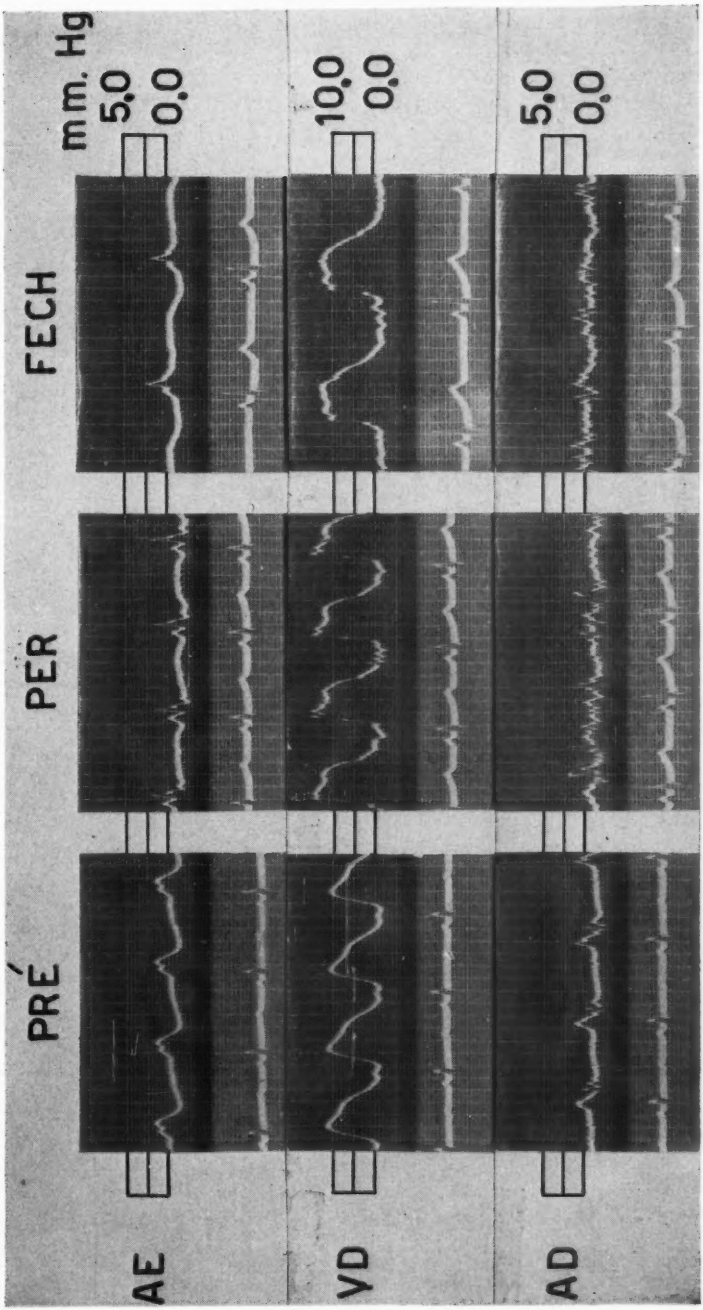

Fig. 8.—Records of intracardiac pressures of Observation No. 36.

TABLE III. SYNTHESIS OF THE RESULTS OF ELECTROCARDIOGRAPHIC RECORDS OF CLASSIC AND UNIPOLAR LEADS OF THE CASES UNDER SINUSAL RHYTHM (Animals operated on at normal temperature)

		WAVE P				INTERVAL P-R		COMPLEX QRS				INTERVAL	
		DURATION (SEC.)	Pc	AMPLITUDE (MM.)	ÂP (DEGREES)	P-R (SEC.)	P-Rc	DURATION (SEC.)	QRSc	AMPLITUDE (MM.)	ÂQRS (DEGREES)	Q-T (SEC.)	Q-Tc
PRÉ	Number of cases	20	20	20	20	20	20	20	20	20	19	19	20
	Values mx	0.055	0.061	8.5	90	0.110	0.119	0.060	0.097	57	95	0.340	0.447
	Values mn	0.030	0.033	2.5	65	0.060	0.066	0.030	0.047	23	20	0.166	0.250
	Arithmetic mean	0.0392	0.0442	5.06	84.3	0.0807	0.0906	0.0465	0.0747	37.4	76.1	0.2158	0.3507
	Standard deviation	0.008	0.009	1.584	6.961	0.013	0.014	0.008	0.013	9.439	20.230	0.029	0.039
PER	Number of cases	18	18	18	18	18	18	18	18	18	16	18	18
	Values mx	0.065	0.068	6.5	95	0.105	0.112	0.060	0.102	49	110	0.382	0.479
	Values mn	0.035	0.037	2.3	80	0.055	0.061	0.035	0.051	12	30	0.196	0.326
	Arithmetic mean	0.0441	0.0478	4.72	89.8	0.0861	0.0942	0.0508	0.0731	28.5	77.8	0.2762	0.4044
	Standard deviation	0.009	0.007	1.304	3.053	0.014	0.014	0.007	0.015	9.313	21.906	0.041	0.042
FECH	Number of cases	15	15	15	15	15	15	15	15	15	13	13	14
	Values mx	0.055	0.062	8.0	115	0.110	0.126	0.060	0.100	51	100	0.316	0.437
	Values mn	0.030	0.032	2.5	70	0.050	0.057	0.040	0.063	19	20	0.214	0.290
	Arithmetic mean	0.0407	0.0448	4.84	90.5	0.0800	0.0891	0.0520	0.0779	30.7	83.5	0.2653	0.3837
	Standard deviation	0.007	0.008	1.391	10.020	0.016	0.018	0.007	0.012	10.688	20.955	0.032	0.036

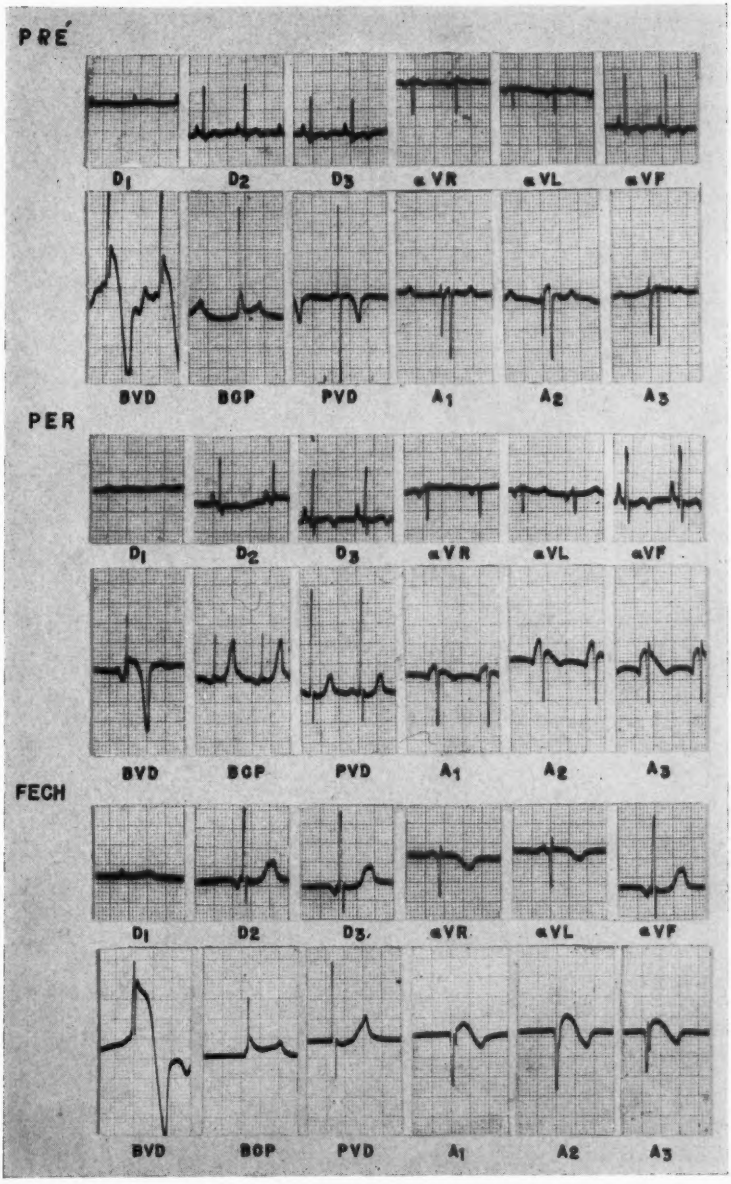

Fig. 9.—Electrocardiographic records of Observation No. 20.

TABLE IV. SYNTHESIS OF THE RESULTS OF ELECTROCARDIOGRAPHIC RECORDS OF CLASSIC AND UNIPOLAR LEADS OF THE CASES UNDER SINUSAL RHYTHM (Hibernated animals)

		WAVE P				INTERVAL P-R		COMPLEX QRS				INTERVAL	
		DURATION (SEC.)	Pc	AMPLITUDE (MM.)	ÂP (DEGREES)	P-R (SEC.)	P-Rc	DURATION (SEC.)	QRSc	AMPLITUDE (MM.)	ÂQRS (DEGREES)	Q-T (SEC.)	Q-Tc
NM	Number of cases	10	10	9	9	10	10	10	10	10	10	10	10
	Values mx	0.040	0.046	7.3	90	0.110	0.118	0.045	0.085	95	110	0.308	0.545
	Values mn	0.030	0.035	3.3	35	0.060	0.069	0.030	0.050	38	60	0.168	0.283
	Arithmetic mean	0.0365	0.0410	5.40	77.2	0.0770	0.0874	0.0365	0.0638	55.5	84.0	0.2028	0.3504
	Standard deviation	0.005	0.008	1.471	16.895	0.014	0.014	0.006	0.010	18.477	13.292	0.042	0.041
PRÉ	Number of cases	10	10	10	10	10	10	10	10	10	10	9	9
	Values mx	0.070	0.073	10.0	115	0.130	0.138	0.080	0.130	92	135	0.658	0.639
	Values mn	0.040	0.048	1.0	–30	0.090	0.104	0.055	0.058	29	65	0.350	0.385
	Arithmetic mean	0.0555	0.0580	4.09	69.0	0.1145	0.1172	0.0640	0.0783	47.9	89.7	0.4184	0.4761
	Standard deviation	0.010	0.015	2.679	41.352	0.016	0.014	0.008	0.020	19.011	18.583	0.104	0.081
PER	Number of cases	7	7	7	7	7	7	7	7	7	7	7	7
	Values mx	0.105	0.106	7.5	90	0.320	0.323	0.100	0.108	47	115	0.786	0.664
	Values mn	0.045	0.052	2.2	80	0.095	0.099	0.055	0.055	19	85	0.423	0.449
	Arithmetic mean	0.0650	0.0657	4.23	87.4	0.1592	0.1604	0.0707	0.0747	31.8	95.7	0.5064	0.5302
	Standard deviation	0.021	0.019	2.155	3.823	0.076	0.076	0.017	0.018	10.930	10.177	0.127	0.070
FECH	Number of cases	4	4	4	4	4	4	4	4	4	4	4	4
	Values mx	0.080	0.079	5.0	120	0.220	0.209	0.110	0.124	47	105	0.652	0.600
	Values mn	0.040	0.041	1.5	80	0.105	0.108	0.080	0.087	16	–60	0.434	0.472
	Arithmetic mean	0.0700	0.0687	3.35	95.0	0.1600	0.1555	0.0950	0.0912	27.5	58.7	0.5565	0.5265
	Standard deviation	—	—	—	—	—	—	—	—	—	—	—	—
AQ	Number of cases	5	5	5	5	5	5	5	5	5	5	5	5
	Values mx	0.040	0.045	10.0	90	0.090	0.124	0.050	0.079	58	120	0.278	0.452
	Values mn	0.030	0.033	3.2	85	0.063	0.070	0.035	0.042	25	85	0.178	0.255
	Arithmetic mean	0.0340	0.0386	5.84	88.4	0.0796	0.0952	0.0390	0.0626	37.8	96.2	0.2122	0.3668
	Standard deviation	0.004	0.015	2.748	2.213	0.015	0.022	0.007	0.017	15.172	14.567	0.042	0.052

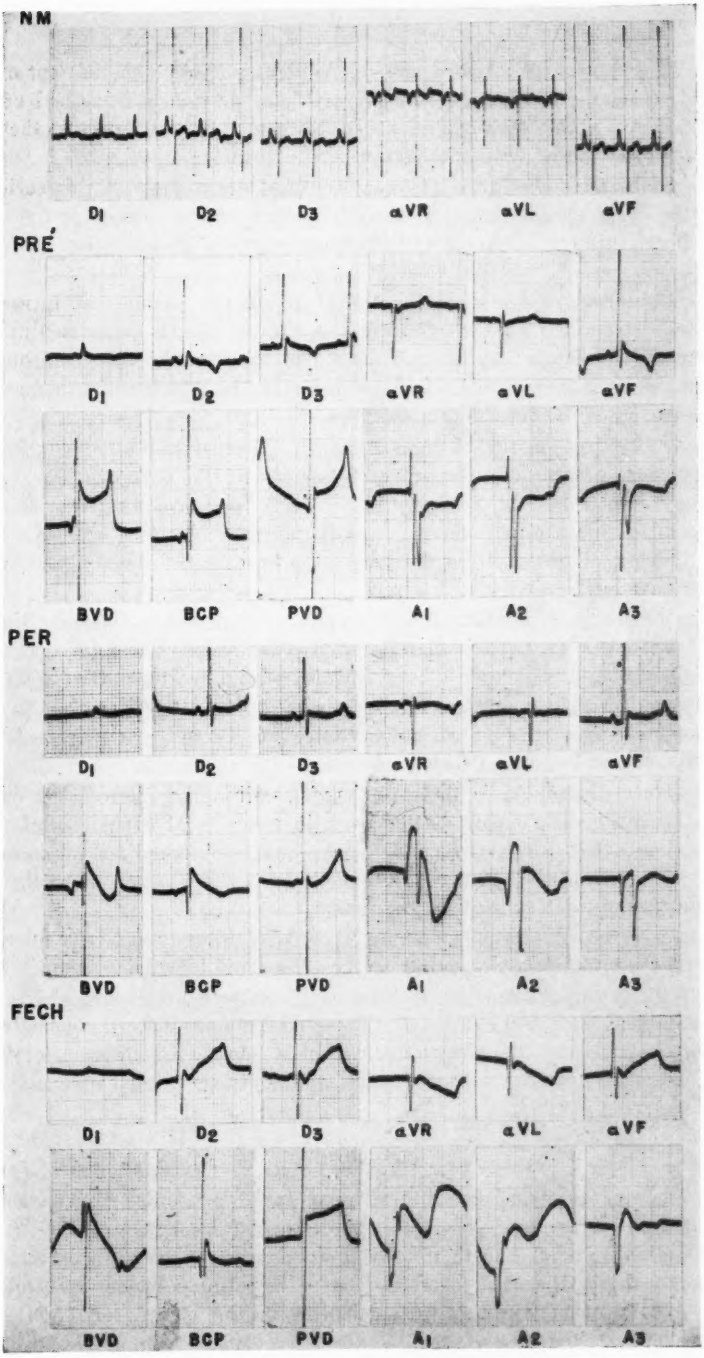

Fig. 10.—Electrocardiographic records of Observation No. 41.

In our experiments, closure of the defect was made by two different methods in the two groups of animals. In one of them, we used the method of Gross (1952), in the other, closure under direct vision. In both groups, the defect was completely closed with three stitches.

Coronary air embolism, a frequent cause of death early in this series, was prevented by placing a Satinsky clamp in such a way as to occlude the outflow of the heart through the aorta and pulmonary artery, and flooding the cardiac and thoracic cavities with saline solution.

Few studies are found in the literature on the changes of intracardiac pressures determined by the creation and closure of the experimental IASD and practically none under hibernation. The study of the instantaneous pressures in the several experimental phases was made by pressure tracings recorded simultaneously with the electrocardiogram.

Some features of the changes induced by experimentation in the right ventricle were observed by the pressure tracings in this cavity.

The correlation test between the average pressure and the frequency demonstrated that the pressure increase of the right ventricle, after production of the defect, was due, not to the frequency but, most probably, to the blood flow increase in this cavity.

The phenomenon explained by Sarnoff and Berglund (1954) as the shift of the heart from one "ventricular function curve" at a certain level to another at a higher level, in which with less filling pressure a greater output is obtained, was observed in one-third of the cases.

The presence of the "form of resistance" of Borges, characterized by the predominance of Ps_2 over Ps_1, was observed.

Electrocardiographic records rendered possible the observation of some electrocardiographic changes of the heart in the several experimental phases. It seems likely that the electrocardiographic changes observed are fundamentally due to the general conditions peculiar to the experiment and not to the hemodynamic changes determined by the defect.

The electrocardiographic changes caused by hibernation were more uniform and their findings are similar to those reported by other authors.

Admitting the existence of a relationship between the electrocardiographic and mechanical phenomena, an attempt was made to correlate the hemodynamic changes observed to the electrocardiographic ones. No Pearson coefficient, statistically significant at the level of one and 5 per cent, was found among the several elements studied.

CONCLUSIONS

1. The creation of a large interatrial septal defect under direct vision was well tolerated by the dog.

2. Clamping of the aorta up to the origins of the coronary arteries and flooding of the cardiac and chest cavities with saline solution were adequate measures to prevent coronary air embolism in the closure of IASD under direct vision.

3. Artificial hibernation, still in the developmental phase, offered favorable conditions for the performance of surgical intracardiac maneuvers.

4. Artificial hibernation induced hemodynamic changes, evidenced by variations in the pressure values and the morphology of pressure curves.

5. There was significant predominance of the mean pressure interatrial gradient from left to right in all the experimental stages in dogs operated on at normal temperature.

6. There was significant predominance from left to right of the interatrial gradient of the B, A′, and Y waves after closure of the IASD, in the series of dogs operated on at normal temperature.

7. The interatrial gradient of the mean and instantaneous pressures showed a significant predominance from left to right in dogs with open chest and intact interatrial septum in the series submitted to artificial hibernation.

8. Significant predominance from left to right of the D-waves interatrial pressure gradient observed in all the experimental stages in both series of animals.

9. Significant changes of the atrial pressures observed in the series of dogs operated on at normal temperature, after creation of the IASD, were: (a) pressure increase of the D wave in the right atrium; and (b) decrease of the D-wave interatrial pressure gradient.

10. Significant changes of the atrial pressures observed in the series operated on under artificial hibernation, after creation of the IASD, were: (a) decrease of mean and instantaneous pressures in the left atrium; (b) increase of the wave pressure in the right atrium; and (c) decrease of the interatrial gradient of the mean and D-wave pressures.

11. Significant changes of the atrial pressures observed in the series of dogs operated on at normal temperature, after closure of the IASD, were: (a) increase of mean and instantaneous pressures in the left atrium; and (b) increase of the interatrial pressure gradient of the D wave.

12. There was a significant increase of the D-wave pressure in the left atrium, in the series of dogs operated on under artificial hibernation, after closure of the IASD.

13. A comparison of the values observed after closure of the interatrial septal defect with those before its production, in dogs operated on at normal temperature, showed: (a) significant increase of the mean and instantaneous pressures in the left atrium; and (b) significant increase of the instantaneous pressures B, D, and Y in the right atrium.

14. Values of the mean and instantaneous pressures A, B, D, and Y observed after closure of the interatrial septal defect, in the series of animals operated on under artificial hibernation, were, in the left atrium, significantly lower than those registered before its creation.

15. No significant changes of the mean values in the right atrium were observed after production and closure of the IASD in both series of animals.

16. Mean and systolic pressures in the right ventricle, before the creation of the interatrial septal defect in animals operated upon under artificial

hibernation, were significantly lower than in those operated at normal temperature and Pd_1 value was significantly higher.

17. There was a significant increase of the mean pressures in the right ventricle, in both series of animals, after creation of the defect and significant decrease after its closure.

18. Systolic and Pd_2 pressures in the right ventricle were significantly increased after production of the IASD, in both series of animals.

19. Significant decrease of systolic pressures in the right ventricle was observed after closure of the defect in the dogs operated on at normal temperature.

20. Significant decrease of cardiac frequency after closure of the IASD was observed in the series of animals operated on at normal temperature.

21. Progressive and significant decrease of cardiac frequency in the various experimental stages was observed in the series of animals operated upon under artificial hibernation.

22. The incidence of supraventricular rhythms of the nonsinusal type was higher after closure of the defect, mainly in animals operated upon under artificial hibernation.

23. Main electrocardiographic changes observed after the production of the IASD, in the series of animals operated upon at normal temperature, were: (a) a tendency toward increase of the P-wave duration; (b) a significant deviation of P-angle to the right; (c) a tendency toward increase of the P-R interval; (d) a tendency toward increase of the Q-T interval; and (e) a significant shortening of the R/S relation obtained by direct epicardial lead and recorded at the base of the right ventricle.

24. Main electrocardiographic changes after creation of the IASD, in animals operated on under artificial hibernation, were: (a) tendency toward increase of the P-R interval; and (b) tendency toward increase of the Q-T interval.

25. No uniform or significant electrocardiographic changes were observed after closure of the IASD in the series of animals operated upon at normal temperature.

26. The comparison of electrocardiographic values observed after closure of the defect to those registered before its production, in the series of dogs operated upon at normal temperature, showed: (a) a tendency toward increase of the Q-T interval; and (b) a significant decrease of the R/S relation recorded at the base of the right ventricle.

27. The morphologic changes in the RS-T segment and T wave observed in animals operated on under artificial hibernation were different from those of animals operated upon at normal temperature and ones usually found in cardiac surgery.

28. The comparison of values registered in dogs at normal temperature to those observed in the same animals after hibernation and with open chest showed: (a) a tendency toward increase in duration of the P waves; (b) a significant decrease of the P-wave amplitude; (c) a tendency toward increase

of the P-R interval; (d) a tendency toward increase in duration of the QRS complex; and (e) a tendency toward increase of Q-T values.

29. In the series of animals operated on under artificial hibernation, there was reversibility of electrocardiographic changes due to the tendency to return, after rewarming, to the values observed before hibernation.

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BRONCHOSPASM IN BRONCHOGRAPHY

THOMAS H. HEWLETT, LIEUTENANT COLONEL, MC, USA,* ANTHONY J. PUGLISI, MAJOR, USAF (MC),** AND WARNER F. BOWERS, COLONEL, MC, USA***
FORT SAM HOUSTON, TEXAS

A LARGE number of patients with chronic cough eventually have bronchographic studies performed to determine the presence of bronchiectasis. Adequate bronchograms offer the only absolute proof of bronchiectasis and serve as the basis for excisional surgery. Although a single bronchogram reveals the anatomic state of the bronchi at the time of film exposure, it does not offer unequivocal proof of irreversible pathologic changes within the bronchi. Those experienced in pulmonary diseases recognize that the bronchogram alone cannot be accepted as the absolute criterion of lung damage or of the need for excisional surgery. The proof of pulmonary damage is reflected in the patient's clinical course.

The interpretation of bronchograms and the decision for excisional surgery is often delegated to the younger men in a training program. Consequently, the possibility of mistaken interpretation of a single bronchogram might result in unwarranted operation. Several factors may produce variations in bronchial filling which render the recognition of bronchiectasis difficult in adequate bronchograms. Among those that are well recognized, the most prominent are acute respiratory infections, emphysema, and atelectasis. Bronchial changes, which have been ascribed to chronic bronchitis or asthma, consist primarily of some degree of mild dilatation of the bronchi with beading and irregularities of caliber noted on bronchogram. Little attention has been directed toward the possibility of bronchospasm occurring during bronchography which suggests that it is rare. The experience at Brooke Army Hospital demonstrates that bronchospasm may account for a bronchogram which is interpreted as showing bronchiectasis.

Seventy-nine bronchographic studies were performed at Brooke Army Hospital over an eighteen-month period. Bronchospasm during bronchography was encountered and proved in 7 patients of this group. The significance of this 8.8 per cent incidence of bronchospasm during bronchography is of interest because the initial radiologic interpretation of these bronchograms was of bronchiectasis, usually bilateral. These patients were not submitted to operation

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*Chief, Thoracic-Vascular Surgery Section; Assistant Chief, General Surgery Service; Assistant Professor of Surgery, Graduate School, Baylor University, Houston, Texas.
**Formerly Surgical Resident at Brooke Army Hospital, now assigned to USAF Hospital, Clarke AFB, Luzon, P. I.
***Chief, Department of Surgery and Chief, General Surgery Service, Brooke Army Hospital, Fort Sam Houston, Texas; Chief, Clinical Surgery, Medical Field Service School; Surgical Consultant, 4th Army Headquarters; Professor of Surgery, Graduate School, Baylor University, Houston, Texas.

because of the presentation of the bronchograms before a combined medico-surgical conference where experienced clinicians disagreed with the diagnosis of bronchiectasis and requested that the bronchographic studies be repeated. The repeat studies carried out on each patient resulted in essentially normal bronchograms. Thus, the value of conference interpretation of films is demonstrated as well as the fallacy of a single bronchographic study in patients whose clinical course, though suggestive of bronchiectasis, is not typical.

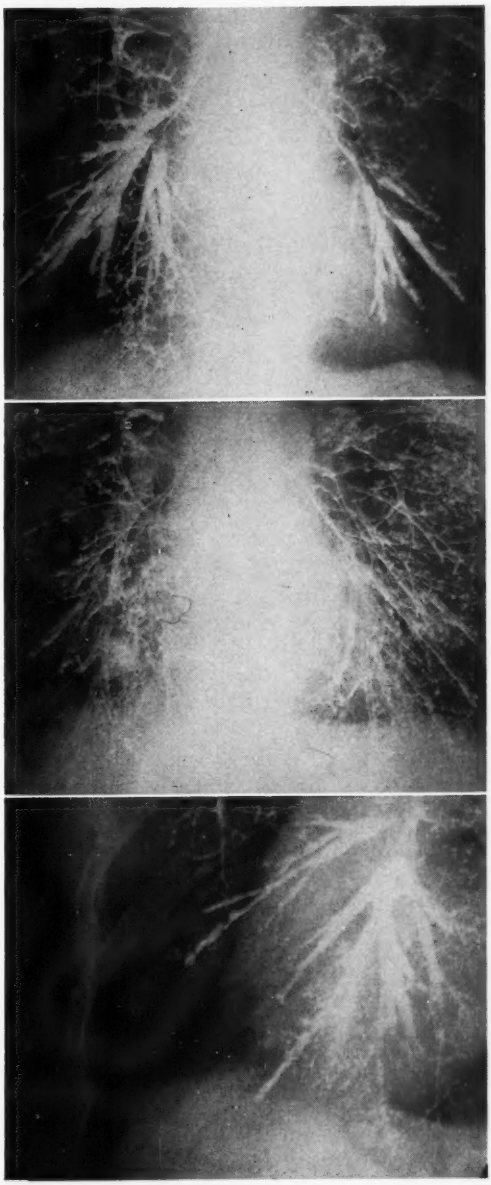
Bronchospasm is usually associated with the asthmatic patient and is most frequently diagnosed on the basis of a history of attacks of respiratory distress characterized by wheezing and the presence of classical râles. Three of the 7 patients observed gave histories which were suggestive of asthma and, in each of the 3, unilateral basilar wheezing was noted on auscultation. It is to be noted that in none of these patients was an excitant proved by allergic studies. Four patients of the group gave histories which were entirely negative for any factor which would suggest the possibility of asthma. One representative patient from each group has been chosen for presentation.

CASE REPORTS

CASE 1.—A 43-year-old white man reported to the outpatient department with a history of episodes of coughing and wheezing for several years. Allergy studies on two occasions had failed to reveal an excitant. Auscultation of the chest revealed localized transient wheezes over the left base posteriorly. Routine posteroanterior and lateral chest films did not reveal any pulmonary abnormalities. Bronchoscopy revealed moderately inflamed granular mucosa in the lower left main-stem bronchus. No spasm or excessive secretion was noted. Bronchograms (Fig. 1, *A, C, E*) performed at this time were reported as demonstrating cylindric bronchiectasis involving the right middle and lower lobes and the left lower lobe. Medico-surgical chest conference disagreed with the diagnosis of bronchiectasis and requested a second bronchoscopic study. Bronchograms were repeated after twenty-one days. The second series of films (Fig. 1, *B, D, F*) were reported as follows: "Cylindrical bronchiectasis previously described in both lower lung fields is no longer apparent on this examination." Immediately following the second bronchogram, this patient developed a generalized urticarial rash relieved by Pyribenzamine. This patient was placed on outpatient medical treatment for chronic asthmatic bronchitis.

CASE 2.—A 23-year-old white man was transferred to Brooke Army Hospital with a diagnosis of "Severe chronic bronchitis, probably on basis of bronchiectasis." History revealed repeated colds and influenza as a child. In 1949, while serving in Japan, he developed an acute bronchitis requiring hospitalization. Slight productive cough persisted as a residual of this illness. Sputum had changed to a yellowish color four months prior to this hospital admission; the volume increased to one-half cup per day. His attacks of bronchitis were characterized by fever, chills, chest pain, and blood streaking of sputum. Response was prompt to antibiotic therapy. Allergic studies did not reveal any excitant. Routine chest films were negative for pulmonary pathology. Physical examination of the chest revealed fine moist râles over the right upper lung field and throughout the left lung field, posteriorly. Scattered expiratory wheezes were noted.

Bronchoscopy was essentially normal. Bronchograms (Fig. 2, *A, C, E*) revealed bronchial dilatation and were reported as consistent with bronchiectasis. Films of the repeat bronchography (Fig. 2 *D, B, F*), performed fourteen days later, reveal normal filling. This patient was discharged on a medical regimen for chronic bronchitis.

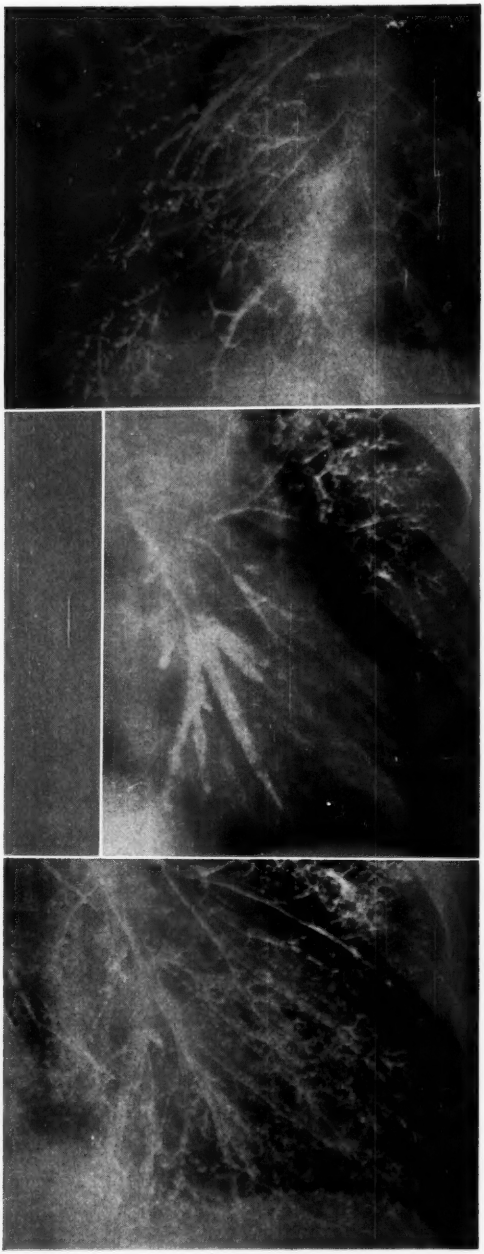


A.

B.

C.

Fig. 1.—*A*, Initial posteroanterior bronchogram, revealing bilateral bronchogram. *B*, Repeat posteroanterior bronchogram, revealing normal patterns. *C*, Left anterior oblique bronchogram, revealing spasm right middle and lower lobes.



D.

E.

F.

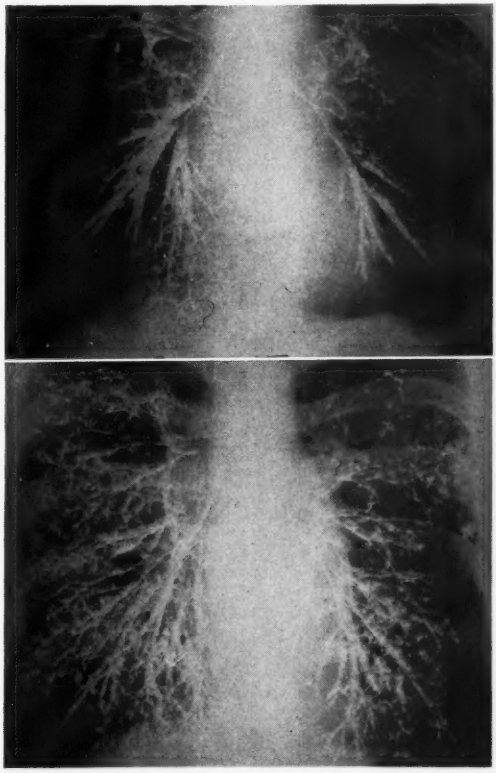
Fig. 1 (Cont'd).—*D*, Repeat left anterior oblique bronchogram, normal pattern. *E*, Initial right anterior oblique bronchogram, revealing spasm of lingula and left lower lobe. *F*, Repeat right anterior oblique bronchogram, normal pattern.

BRONCHOGRAPHY TECHNIQUE

Oral intake was withheld for a period of 4 to 6 hours. Nembutal, 1½ grains, was administered orally 1½ hours prior to the bronchography.

Immediately before the procedure, the patient received 100 mg. Demerol and 1/150 grain atropine, intravenously. Topical anesthetization was accomplished by spraying a freshly prepared solution of 0.5 per cent Pontocaine solution with 4 drops of 1:1000 epinephrine per ounce. Particular care was taken to anesthetize thoroughly the pyriform sinuses, the glottis, epiglottis, and vocal cords prior to instillation of the anesthetic agent into the trachea.

A.



B.

Fig. 2.—*A*, Initial posteroanterior bronchogram, revealing bilateral spasm. *B*, Repeat posteroanterior bronchogram, normal pattern.

Anesthetization should not be hurried. Two cubic centimeters were injected through the laryngotracheal opening into each side of the pulmonary tree and 2 c.c. were deposited on the carina. Routine bronchoscopy was performed. Bronchoscopy was routinely carried out on new patients referred for study to obtain an accurate picture of the bronchial mucosa.

A No. 16 rubber catheter was passed through the lumen of the bronchoscope. As the bronchoscope was withdrawn, the distal end of the catheter was positioned just proximal to the carina.

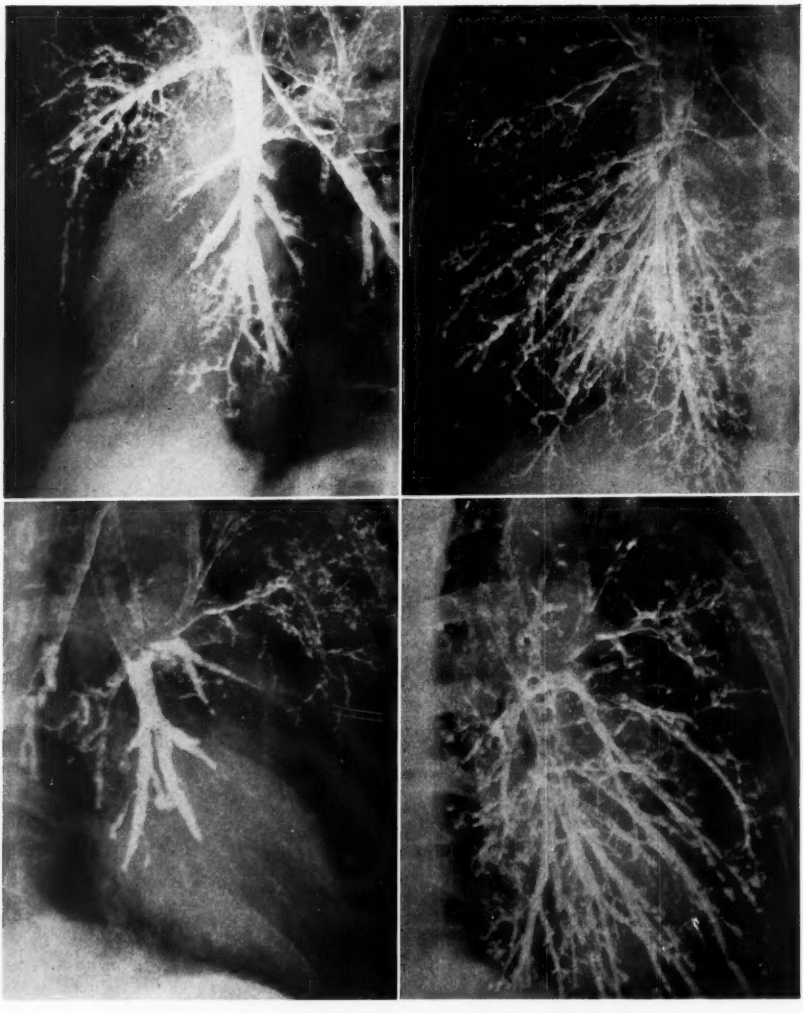


Fig. 2 (Cont'd).—*C*, Initial left anterior oblique bronchogram, revealing spasm right middle and lower lobes.

D, Repeat anterior oblique bronchogram, normal.

E, Initial right anterior oblique bronchogram revealing spasm left lower lobe and lingula.

F, Repeat right anterior oblique bronchogram, normal pattern.

Approximately 5 c.c. of warm Lipiodol was injected during each of the four routine positions used for lobar filling. The catheter was removed after the wet films were reviewed for adequacy of filling.

Repeat bronchography, in the cases presented, was carried out by a technique altered to minimize (1) allergic response to drugs, (2) inadequate sedation, (3) inadequate anesthesia, and (4) trauma resulting from bronchoscopy.

Sedation was increased to 3 grains Nembutal. Demerol and atropine dosage was not increased. Topical anesthesia was accomplished by spray technique using a Pontocaine HCl aerosol solution composed of 0.5 per cent Pontocaine, 2.0 per cent glycerine, 0.01 per cent Triton H_2O, and 0.01 per cent epinephrine. This is essentially a detergent type of topical anesthetic which reduces the surface tension of secretions permitting a better contact between mucosa and anesthetic solution. A No. 16 catheter was passed by indirect vision technique. Lipiodol in 22 c.c. volume was used as contrast medium.

The second bronchography, utilizing increased sedation and improved topical anesthesia, gave normal bronchial patterns.

DISCUSSION

Typical cases of bronchospasm occurring during bronchography have been presented. Prior to repeat bronchography, the probable causes of bronchospasm were considered and the technique altered accordingly. Allergic response to drugs, inadequate sedation and anesthesia, and irritation of bronchoscopy were felt to be important factors in production of spasm. From the standpoint of contact allergic response, Lipiodol cannot be considered the excitant as it was used in the second study, further, the usual reaction to iodine is usually a more generalized one. Inadequate sedation is usually manifest by lack of cooperation and frequent coughing, which was not noted in any of these patients. The more efficient topical anesthesia used in the second study was possibly of significance in eliminating a spastic element. In no instance was initial bronchoscopy traumatic and certainly the areas of marked spasm were beyond the reach of the bronchoscope, in the secondary and tertiary divisions of the lobar bronchi.

The phenomena of spasm during bronchography should be more generally appreciated by those who will be responsible for the diagnosis and treatment of patients with chronic cough. Though such a picture might be anticipated in a small percentage of patients with an asthmatic history, it is of importance to recognize the bronchographic pattern of spasm in the nonasthmatic individual. It seems advisable to review the basic points characteristic of both bronchospasm and bronchiectasis in order to alert the unwary to the possibility of confusing the two conditions.

The cases presented clearly demonstrate the fallacy of a single bronchographic study and show how bronchospasm misinterpreted as bronchiectasis might easily lead to unwarranted excisional surgery.

The bronchographic picture attributable to bronchospasm is characterized by the following features:

1. Bronchial dilatation of a hydrostatic nature occurs within the primary and portions of the secondary division bronchi.
2. Spasm of the tertiary and distal bronchi produces a horizontal obstruction to the flow of the contrast medium, consequently the spastic bronchi do not fill.
3. The normal space relations are maintained between the first and second division bronchi indicating the existence of aerated lung parenchyma.
4. Bronchiolar and alveolar filling is only patchy when evident distal to the zone of dilatation.
5. Proximal narrowing of a major bronchus is never visualized.

The following characteristics are essential to the bronchographic recognition of bronchiectasis:

1. Cylindric dilatation of a marked degree with complete loss of normal tapering tendency,
2. Saccular areas in direct continuity with the dilated bronchus,
3. Crowding of the bronchi resulting from decreased space occupied by pulmonary parenchyma of that involved area,
4. A decrease or complete absence of bronchiolar and alveolar filling, and
5. Proximal bronchial narrowing may or may not be evident.

The horizontal obstruction to flow evident in the initial bronchogram is not encountered in the markedly dilated bronchus of bronchiectasis. The maintenance of normal space relations between the several bronchi as determined by their position and direction in bronchospasm is not evident in bronchiectasis wherein the functionless parenchyma permits a crowding and downward depression of the bronchi. These particular points are basic in differentiation of bronchospasm and bronchiectasis.

CONCLUSIONS

1. Repeat bronchography is essential in establishing the differentiating bronchial distention due to spasm from bronchiectasis.
2. Conference consideration of bronchograms is of value in preventing unnecessary surgery which might result from misinterpretation of a single bronchographic study.

SIMULTANEOUS BILATERAL RESECTION WITH A SPACE-DIMINISHING PROCEDURE FOR PULMONARY TUBERCULOSIS

VIKING OLOV BJÖRK, M.D.
STOCKHOLM, SWEDEN

ALREADY in 1952, Overholt showed that simultaneous bilateral segmental resection could be performed. In 1956, he reported ten such operations without mortality. Lewis and associates had, by 1956, operated on 16 patients on both sides, simultaneously, without mortality. So far, for pulmonary tuberculosis, only patients requiring no more than segmental resections on each side have been reported. I have had 4 cases of pulmonary tuberculosis in which more extensive bilateral resections necessitated a space-diminishing procedure as well. All patients have tolerated well this rather large operation in one sitting. The postoperative treatment must be carefully supervised.

TECHNIQUE

Lewis and his associates have recommended a supine position with the use of a transverse anterior incision through the third interspace, bilaterally, and a transverse division of the sternum. This incision seems convenient in their material where no more than segmental resections were required on each side. The postoperative separation of the sternum in 3 cases of 16 will, however, make one hesitate to use this approach in tuberculosis. Overholt's recommendation to use the face-down position, with bilateral subcostal incisions, is preferable in most cases for the following reasons:

1. After the resection on the first side, it may be found unwise to proceed with both resections simultaneously.

2. After more extensive resection, it may be found desirable to perform a space-diminishing procedure on one side. It seems to be easier to perform an osteoplastic roof thoracoplasty or a diaphragm plastic in the face-down position.

It is important to avoid a narrow angle between the two incisions otherwise a necrosis of the skin will follow in that angle (Figs. 1 and 2).

CASE REPORTS

CASE 1.—The patient, a 25-year-old woman, had had bilateral cavitary tuberculosis for four years (Fig. 3). The maximal breathing capacity was 62 L. per minute. Residual capacity was 31 per cent of the total capacity. Bronchospirometry showed an oxygen uptake of 80.4 per cent and a ventilation of 73.7 per cent of the total on the right side.

From Sabbatsberg Hospital; Surgeon in Chief: C. Crafoord, M.D., Professor. St. Göran Hospital; Physician in Chief: A. Westergren, M.D., Professor. Uttran Hospital; Physician in Chief: N. Levin, M.D.

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The operation was performed in the face-down position. On the right side the upper lobe could be freed intrapleurally and then resected. The remaining lung parenchyma was of a good quality with only a few small hard nodules in the middle and lower lobes. When the right chest was closed, the left was entered through a subcostal incision under the fifth rib. It was necessary to remove the whole left upper lobe and the superior segment of the lower lobe in the extrapleural plane in one piece. Traction dissection could not be used due

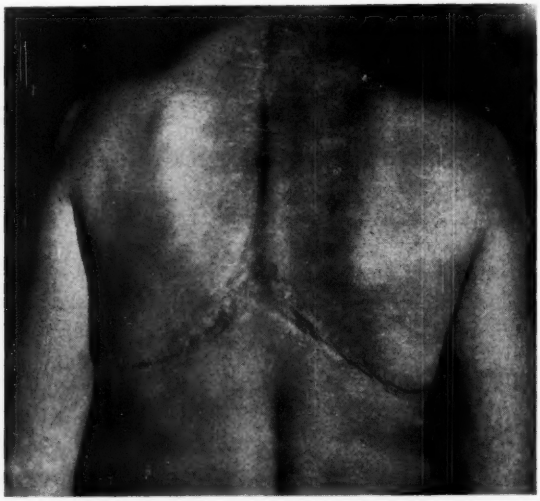


Fig. 1.—Photograph of the incision in Case 2. There was too sharp an angle between the two incisions resulting in a necrosis of the skin with a retarded healing.

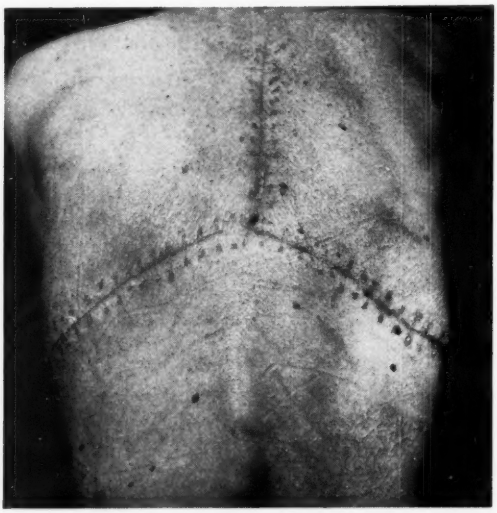


Fig. 2.—Photograph of the incision in Case 4. Here the incision was ideally placed and healed by primary intention.

to fibrotic changes in the lower lobe. It was necessary to go between clamps around the cavitary disease in the left lower lobe. In the remaining left basal segments, there were several small nodules. Due to the relatively small amount of remaining lung tissue which was fibrotic and contained tuberculous nodules, I considered the addition of a left osteoplastic thoracoplasty in the same sitting a necessity. The second to fifth ribs were resected posteriorly and then fixed to the sixth rib with nylon sutures through drill holes. Immediately after completion of the operation, a tracheostomy was performed and the patient connected to an Engström respirator. One day after the operation, she could take over ventilation herself for ten minutes and after nine days she did not need the help of the respirator any more.

Fig. 3.—Case 1. X-ray of the lungs demonstrating large tuberculous cavities in both upper lobes as well as in the superior segment of the left lower lobe.

She regained strength rather slowly after the operation and had herpes zoster complicating the convalescence. One year after the operation she was in a very good general condition (Fig. 4).

CASE 2.—The patient, a 33-year-old man, had had bilateral cavitary tuberculosis for one year. His general condition was good. Maximal breathing capacity was 158 L. per minute. Bronchospirometry showed 53 per cent of the total ventilation on the right side.

At operation, the apicoposterior segment of the left upper lobe was removed. There were widespread nodules to be palpated in the lingula and in the lower lobe. An osteoplastic thoracoplasty with fixation of ribs 2 to 5 down to the sixth rib was added. The operation

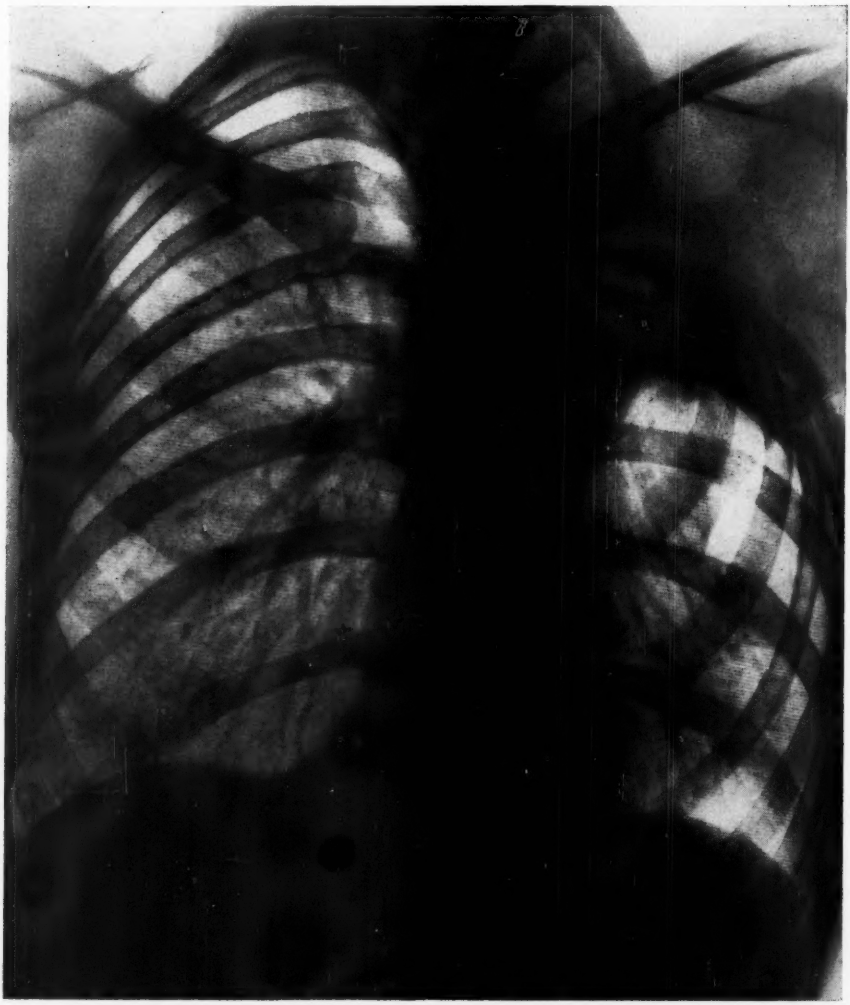


Fig. 4.—Case 1. X-ray of the lungs one year after simultaneous resection of the right upper lobe, left upper lobe, and superior segment of the left lower lobe, as well as an osteoplastic thoracoplasty on the left side.

Fig. 5.

Fig. 6.

Fig. 5.—Case 3. X-ray of the lungs demonstrating tuberculous cavities in both upper lobes and the lower lobe on left side.
Fig. 6.—Case 3. X-ray of the chest five months after simultaneous resection of the right upper lobe, the apicoposterior and anterior segments of the left upper lobe, as well as the superior and posterior basal segments of the left lower lobe, and a diaphragm plasty on the left side.

was continued with a resection of the right upper lobe. The remaining parenchyma on the right side was in a good condition with only a few palpable nodules. The patient withstood the operation well and took over spontaneous ventilation immediately after the procedure.

CASE 3.—The patient, a 46-year-old woman, had had bilateral tuberculosis for twenty-five years. There had been a progression in the past year with bilateral cavitation (Fig. 5). The maximal breathing capacity was 79 L. per minute. The residual capacity was 30.5 per cent of the total capacity. Bronchospirometry showed 57.4 per cent of the total oxygen uptake on the right side.

At operation, the left side was first explored through a subcostal incision under the fifth rib. The apicoposterior and anterior segment of the left upper lobe as well as the superior and posterior basal segments of the left lower lobe were resected. Due to the rather extensive resection on the left side, it was decided to diminish that thoracic cavity. The diaphragm was therefore mobilized and resutured to the fifth intercostal muscle. Then the right chest was opened through a subcostal incision under the sixth rib. The whole right upper lobe was resected. Small nodules could be palpated in the lower lobe.

During the operation on the left side, an accident occurred. Some air entered the right side of the heart through the intravenous drip. The whole of the left pulmonary artery was full of air and its pressure rose considerably. The artery was immediately punctured by a wide bore needle and all air removed. After the evacuation of air, the pulmonary artery pressure decreased to 20 cm. water. After this experience, I think it is advisable to make a speedy opening of the chest and of the pulmonary artery in cases accidentally receiving too much air by an intravenous drip.

Two intrapleural tubes for drainage were left on each side. Immediately after the completion of the operation, a tracheostomy was performed and the patient connected to an Engström respirator. After two days, the patient could take over the ventilation for short intervals of ten minutes, but after twenty-four days she could definitely be without the respirator. The patient had a prolonged period of postoperative fever, but was able to leave the hospital two months after the operation in good condition (Fig. 6).

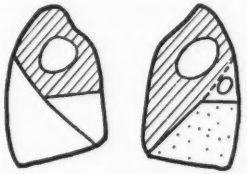
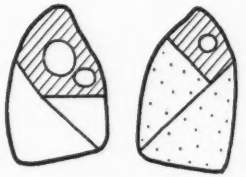
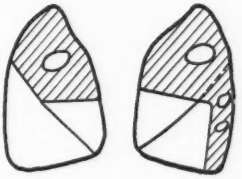
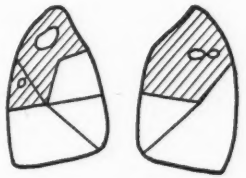
CASE 4.—The patient was a 43-year-old man who had had bilateral apical tuberculosis for sixteen years with bilateral cavitation for one year. The maximal breathing capacity was 98 L. per minute. Bronchospirometry showed 53 per cent of the total oxygen uptake and 48 per cent of the ventilation on the right side.

At operation, the right side was explored through a subcostal incision under the fifth rib. The apical and posterior segments of the right upper lobe and the superior segment of the right lower lobe were removed. The remaining lung parenchyma on the right side looked rather emphysematous. The diaphragm was mobilized and resutured to the fifth intercostal muscle bundle. Then the incision was extended to the left side and the apicoposterior and anterior segments of the left upper lobe were resected at the same operation. The patient made an uneventful recovery and had no difficulty in spontaneously maintaining an adequate ventilation.

DISCUSSION

In cases of bilateral tuberculous cavitation where surgical treatment is being considered, a simultaneous resection should be seriously discussed. The addition of a space-diminishing procedure, either an osteoplastic thoracoplasty[2] or a diaphragm plasty[6] on one side, need not be a contraindication to a simultaneous bilateral resection. It is wise to explore the side with the more extensive disease first, using the face-down position. After completion of the first side it can then be decided whether it would be wise to proceed with the other side. Preoperative lung function studies with determination of the maximal breathing capacity and the oxygen uptake and ventilation on each side are helpful in

TABLE I. SIMULTANEOUS BILATERAL RESECTION WITH SPACE-DIMINISHING PROCEDURES

Resection: Right upper lobe + left upper lobe + superior segment left lower lobe + left osteoplastic thoracoplasty. Postoperative respirator treatment for 9 days.		Case 1.
Resection: Apicoposterior segments left upper lobe + right upper lobe + left osteoplastic thoracoplasty. Spontaneous ventilation postoperatively.		Case 2.
Resection: Right upper lobe + apicoposterior and anterior segments left upper lobe + superior and posterior basal segments left lower lobe + left diaphragm plasty. Postoperative respirator treatment for 24 days.		Case 3.
Resection: Left apicoposterior and anterior segments + right apical and posterior segment upper lobe + superior segment right lower lobe + right diaphragm plasty. Spontaneous ventilation postoperatively.		Case 4.

making the decision. The patient will gain several months in shortened hospital stay and have much less discomfort than in a staged procedure. Furthermore, the postoperative treatment of breathing exercises may be more difficult when cavitary tuberculosis remains on the contralateral side after operation.

Only carefully selected patients should be chosen for simultaneous bilateral resections. One need not hesitate to add a space-diminishing procedure at the same time. Naturally, this extensive pulmonary surgery should only be undertaken when the facility for postoperative respirator treatment is at hand.[5] It may be found necessary to relieve the patient from the respiratory work and ensure adequate ventilation for some time in the immediate postoperative period.

SUMMARY

Four cases of simultaneous bilateral resection are reported. The resection has been extensive enough to warrant a space-diminishing procedure at the

same operation. In 2 cases, an osteoplastic thoracoplasty and in 2 a diaphragm plasty were added. In 2 cases, the spontaneous ventilation was adequate, but in 2 it was necessary to add respirator treatment during the postoperative period. All 4 patients withstood the procedure well. A careful selection of patients is necessary.

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PECTUS EXCAVATUM: A SURVEY AND A SUGGESTION FOR MAINTENANCE OF CORRECTION

E. Harrison Griffin, M.D., and J. F. Minnis, Jr., M.D.
Brooklyn, N. Y.

Brauhinus,[1] in 1594, described the clinical condition of chonechondrosternon. Since then, this deformity has been recognized by various names: chonechondrosternon, trichterbrust, chondosternal depression, funnel chest, and pectus excavatum; the first three being the more descriptively accurate, the last, the more commonly accepted term. Pectus excavatum may be described as a depression deformity of the body of the sternum and costal cartilages beginning at or inferior to the manubriogladiolar junction and reaching a maximum at the xyphoid. The classical picture is that of a "round-shouldered, hollow-chested, and pot-bellied" child.[2]

The generally accepted incidence is 0.06 per cent, with males predominating by a ratio of four to one.[3]

A familial tendency has been demonstrated by Lester[2] and Sainsbury,[4] who believes that the defect is usually recessive; although, in one family, a dominant character was apparent. Most authors,[4-8] with the exception of Effler,[9] believe the deformity is congenital. Brown and Cook[10] reported associated anomalies in 31.8 per cent of their series of 44 cases. The consensus has been that pectus excavatum is a progressive disease;[6-13] however, Gross[14] has stated that "there are many babies in whom the deformity does not progress. . . ."

ETIOLOGY

Various theories of historical interest regarding the etiology of pectus excavatum have been described by Ochsner and DeBakey:[3] arrested development of the sternum, hereditary syphilis, rickets, constitutional anomaly due to degenerative disease, poor posture, etc. Flesch[15] suggested, in 1873, that funnel chest was caused by an overgrowth of the ribs. As late as 1944, Sweet[16] and others gave some credence to this theory.

In 1939, Brown[13] presented a feasible explanation of the causal mechanism in his "substernal ligament" or "central tendon" theory, and opened a new approach to the surgical alleviation of this deformity. The substernal ligament has been designated as ligamentous fibers from the transversus thoracis and membrana sterni which merge posteriorly (retroxyphoid) to form the linea alba.[13] The central tendon of the diaphragm is a thin, strong aponeurosis located at the center of the diaphragmatic vault. It lies in close proximity to the xyphisternum and costal arch to which it is attached by rather short muscular

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fibers. This point of attachment is shared with the substernal ligament. Therefore, any abnormal shortening of the anterior fibers and central tendon would cause depression of the lower end of the infant sternum, particularly during inspiration. Brown and Cook[10] have proposed that in funnel chest there is a neuromuscular imbalance whereby the anteroposterior fibers of the diaphragm are overstimulated. Asymmetrical deformity may be explained on the basis of overstimulation of one rather than both phrenic nerves.

Brodkin[8] has not been able to demonstrate the "retrosternal ligament" and proposes anomalous deformity of the diaphragm as etiological. The normal diaphragm is composed of "four major muscular divisions derived from the anterior septum transversum, the two lateral pleuroperitoneal membranes and the dorsal mesentery. Each, separated by a raphe, insert into the central trefoil tendinous portion. Contraction causes descent of the diaphragm without pull on any part of the chest wall. These contractions are responsible for the normal changes in development of the round thorax of the infant to the elliptical during the first year of life."[8] In chondrosternal depression deformity, the anterior portion of the diaphragm is tendinous showing a paucity of muscular fibers.[7] Retraction of the anterior chest wall during inspiration is produced by contraction of the diaphragm. This is the result of the pull of the tendinous attachment on the gladiolar-xyphoid junction of the sternum. Asymmetrical maldevelopment of the muscular diaphragm results in asymmetrical funnel chest.

Pectus excavatum, with paradoxical sternal retraction, may be noted at birth. Ravitch[5] has found it difficult to implicate the substernal ligament as entirely responsible because fetal respiration probably does not exert sufficient force to produce such a deformity. Other authors[2, 5, 9, 12, 17, 18] consider faulty function or development of the central tendon to be etiological.

A final etiological factor is that based on upper respiratory obstruction. First proposed by Holt,[19] and later supported by Hollinger,[20] it may be explained in the following quotation: "Shortening of the diaphragm is initiated as a result of forced respiratory efforts to overcome an obstruction somewhere between the carina and nose or mouth. The negative pressure thus produced causes a depression of the sternum because the cartilaginous portion of the chest is its weakest area. This leads to a contracture of the diaphragm which eventually becomes permanent."[19] It is generally recognized that respiratory obstruction may cause depression of the sternum with even marked paradox in infancy. We believe that this deformity is a separate entity and should not be confused with pectus excavatum. Probably this theory is only a contributory factor; however, Lester[2] has suggested that any obstruction to the respiratory tract be corrected prior to attempting reparative surgery for the pectus excavatum. Decrease in the anteroposterior diameter of the thorax, found in this deformity, impedes elevation of the ribs, and effectively prevents satisfactory clearing of the tracheobronchial tree.[10] Thus, an obstructive mechanism may be initiated secondary to costosternal defect.

MANIFESTATIONS

The clinical manifestations of pectus excavatum are of three types: cosmetic, orthopedic, and cardiorespiratory. The patient presents with a flat, thin chest and a depression deformity of the thorax anteriorly; there is dorsal kyphosis, and the head is thrust forward. He, and especially she, is often shy and retiring due to the distorted habitus which provides a real psychologic problem.

The development or occurrence of cardiorespiratory symptoms are dependent upon four factors[10]: (1) position assumed by the heart, (2) total decrease in the anteroposterior diameter, (3) degree and shape of the depression of the sternal segments, and (4) age. Respiratory complaints may be noted at any age. During adolescence, the pyschologic and orthopedic problems are prominent. So-called "cardiac" symptoms become apparent during the second decade and are progressive with advancing years.

Lindskog[18] has stated that a minority of patients have symptoms resulting from the deformity. Most investigators report that a *majority* have respiratory complaints. This may be explained by impeded elevation of the ribs[10] and/or impaired action of the diaphragm[2, 17] which results in ineffectual cough and poor tracheobronchial toilet. Bronchiectasis may be a late complication of funnel chest.[21] Lester[17, 22] stated that the residual air was increased and the lung volume decreased (over 25 per cent) in proportion to the deformity but seldom to critical levels. Brodkin[6] likewise reported that vital capacity was diminished to as low as 50 per cent; however, in the series of Brown and Cook,[10] the vital capacity was essentially normal. They found the maximum breathing capacity to be the most valuable pulmonary function test: eleven of 40 patients showed a maximum breathing capacity of 50 per cent of the predicted normal and the average improvement following repair of the pectus excavatum was 31 per cent. Oxygen uptake is generally within normal limits as is oxygen saturation. Diminished maximum breathing capacity and/or electrocardiogram changes may be present even though cardiorespiratory symptoms are not apparent.[10] Since this disease is progressive, patients accommodate to the gradually impaired pulmonary function and therefore infrequently offer complaints referable to the dysfunction that exists. In some cases, there may be little or no actual limitation. Indeed, Manning[23] has reported the history of a Canadian prize fighter with definite pectus excavatum who presented no evidence of pulmonary or cardiac embarrassment.

Cardiac disease, other than that attributable to the thoracic deformity, has been reported as occurring "frequently."[10] Such an incidence would be dependent, in part, on the age groups included in the series. Ravitch,[11] Brodkin,[8] Gross[14] and others believe that cardiac symptoms are rare in infancy. Development of symptoms is dependent on: (1) pressure exerted directly on the heart, (2) cardiac compression, and (3) dsplacement of the heart, with possibly subsequent torsion or angulation of the great vessels. The pressure on the heart cannot be evaluated by the degree of sternal deformity. In a majority of instances the heart is displaced to the left and rotated posteriorly.

Hutcheson[24] has reported several cases in which the heart was markedly deviated into the left hemithorax without any evidence of embarrassment. Ravitch[11] has stated that arrhythmia resulted from direct pressure effects and that displacement or compression of the heart lead to mechanical interference with cardiac function. Circulation time and venous pressure are normal.[10] Brodkin[8] has been impressed with the relatively frequent presence of an orthostatic blood pressure and pulse, which have returned to normal postoperatively. The literature does not corroborate this finding. Often there is a systolic murmur which is probably functional.[22] The electrocardiogram demonstrates no specific type pattern. Most common findings are right axis deviation,[8, 11, 12, 18] sinus arrhythmia, low voltage, and inverted T waves in Leads III and IV.[8] Often these abnormalities will revert to normal postoperatively. Dorner[25] reported the case of a 28-year-old man who showed: supraventricular tachycardia with a 5:1 to 1:1 block, palpitation, right heart strain, peaked P waves, tricuspid murmur, and distortion of the tricuspid valve (angiocardiographically) presumably due to compression of the right atrium. Following plastic correction of the pectus excavatum, the electrocardiogram, chest x-ray, and angiocardiogram showed none of the previous abnormalities.

MANAGEMENT

Nonsurgical methods have long been outmoded; belts and other such appliances have been discarded in the correction of pectus excavatum. Yet, as late as 1938, Cotton,[26] in his discussion of a paper by Truesdale,[27] strongly advocated breathing exercises rather than surgery.

The indications for surgery are cosmetic, orthopedic, and physiologic. Quite naturally, all patients have a cosmetic defect. If the disease is permitted to progress, most persons will become round-shouldered, the head will be thrust forward, and kyphoscoliosis may present a problem. It is apparent that every patient has *an* indication for surgery when a diagnosis of funnel chest is made. The only point of contention is *when* should he be subjected to surgical repair. Often the physiologic indications, primarily cardiorespiratory disturbances, dictate the time of intervention. Lester[17] has advocated "early" surgical repair if the patients "have or are about to develop symptomatic and functional disturbances." Brown and Cook[10] have proposed waiting until after the eighteenth month. Gross[14] has suggested that operation be deferred until the third or fourth year. In our review of the literature, the youngest patient reported was three months[11] and the oldest, 40 years of age.[2]

Surgical Corrections.—Ludwig Meyer,[28] operating in 1911, was probably the first to attempt a surgical correction of trichterbrust. His patient was a young adult having cardiac symptoms. The procedure consisted of resection of the second and third costal cartilages on one side. In 1913, Sauerbruck,[29] having a similar patient, successfully resected the right costal cartilages and anterior ribs from the fourth rib to the costal margin. The result was so satisfactory that he subsequently repeated this procedure on 3 patients. Hoffmeister,[30] in 1927, described the Lexter operation; the sternum and attached

costal cartilages were resected, turned over as a plate, and resutured to the rib ends. Alexander[31] reported using a "T" shaped sternotomy in the treatment of a case of traumatic pectus excavatum in 1931. That same year, Sauerbruck[3] devised a plastic repair; resection of the fourth to eighth costal cartilages bilaterally and then elevating the body of the sternum by traction apparatus attached to an overhead frame. In 1933, Carr[32] reported that Jerome Head[33] successfully performed an operation similar to that utilized by Sauerbruck, except that the body of the sternum was transected and then elevated by traction.

With the publication of Brown's[13] classical description of the anatomic basis for and the surgical treatment of pectus excavatum, operative management of this deformity became established. He proposed two operations; one for the incipient stage in infancy and the other for the fully developed stage. The former has been termed the "simple" operation, advocated in children under the age of 2½ to 3 years. The latter is known as the "radical" operation, utilized in older children and adults where the deformed costal cartilages have become fixed in the chondrosternal defect.

The "simple" operation consists of simple division of the posterior ligamentous attachments to the sternum and xyphoid process. As originally described[13] and presently widely utilized,[9, 10, 13, 17, 18, 34] the xyphisternum and retrosternal ligaments are divided. Following these procedures, if the cartilages show little or no deformity, the wound is closed without dividing cartilages or using traction apparatuses. Variations have been described[8, 10, 17] but all follow the principle of separating the central tendon and retrosternal ligament from the body of the sternum. Gross[14] has stated that he does not believe that simple division of the substernal ligament is sufficient to provide correction in more serious cases. Lester[17] limits the use of this operation to infants under one year of age (only 2 have required further surgery), Brown and Cook[10] to those under 2 to 2½ years, and Brodkin[8] to those under 2½ years.

The "radical" operation consists of the "simple" procedure plus three added steps: (1) division, with or without resection, of the costal cartilages bilaterally, usually from the third to the eighth or ninth ribs, (2) transverse cuneiform osteotomy involving the anterior table of the sternum at a level with the third or second costal cartilage, and (3) elevation of the gladiolus. Some form of this procedure has been almost universally adopted by American surgeons.

The more prominent variations are listed:

Brown and Cook[10]: Resection of costal cartilages bilaterally, usually from the third to eighth; anterior transverse sternotomy; division of the xyphisternum and substernal ligaments; external wire traction-elevation of the sternum in an overcorrected position.

Brodkin[8]: Resection of segments of cartilages from the costal arch to the second rib; the xyphoid process is excised; diaphragm is separated from the anterior attachment at the medial ends of the lowest cartilages and may be sutured to the free edge of the recti muscles; in complete anterior transverse

sternotomy; after elevation of the sternum, a costal cartilage free graft is placed beneath the lower end of the gladiolus, bridging the gap between the two hemithoraces anteriorly; all divided cartilages are sutured; no external traction apparatus is used because the sternum now rests on the cartilage graft.

Lindskog[12]: Resection of deformed costal cartilages; anterior transverse sternotomy; division of the diaphragmatic attachments to the xyphisternum without disarticulating the xyphoid process; elevation of the gladiolus in overcorrected position with wire suture traction.

Ravitch[11]: Resection of all re-formed costal cartilages; disarticulation of the xyphisternum, division of substernal ligament; anterior cuneiform osteotomy of the sternum as high as the most superior resected cartilage; the body of the sternum is elevated and held in this corrected position by silk sutures placed at the site of osteotomy; no traction apparatus is employed.

Gross[14]: Division of the xyphisternal articulation and substernal ligament; bilateral double wedge-excision of diseased costal cartilages; anterior transverse sternotomy and, occasionally, longitudinal sternotomy; elevation of the gladiolus and suture of wedged cartilages and sternum in the corrected position; external wire traction is used to maintain the sternum in its corrected position.

Dailey,[35] in 1948, was probably the first to utilize buried elevation support for the freed sternum rather than external traction. A rib graft was anchored to the anterior surfaces of the second right rib and the third left rib, passing beneath the elevated sternum. The result was quite satisfactory. This procedure was advocated for use in those patients who had attained major growth. Adams,[36] Woods, Overholt, and Bolton,[37] and Dorner, Keil, and Schissel,[25] later also utilized the substernal rib strut. Miscall[38] reported his unfortunate experience in the use of buried, crossed Kirschner wires for sternal elevation.

With his vast experience of 94 operations for pectus excavatum in 90 patients, Lester[17] has proposed three operations: "simple," "radical," and "modified" radical. The "simple" and "radical" procedures are essentially the same as described by Brown;[10, 13] the "simple" is reserved for infants under 12 to 14 months of age; the "radical" for those over 2½ to 3 years of age. Those infants who fall in the intervening age group are the ones for whom the "modified" operation was devised. It is similar to the "radical" procedure except that the third and fourth rib cartilages are not divided and the sternotomy is performed at a level with the fifth rather than the third rib.

COMPLICATIONS

The most frequent operative complication is pneumothorax. Bleeding may be profuse; however, frank hemorrhage is quite uncommon.

Complications noted in the postoperative period are primarily those attendant with pneumothorax-atelectasis, pleural effusion, empyema. Paradoxical respiration may present a problem should there be inadequate stabilization of the sternum. Wound infection and keloid formation are sometimes found; the latter being encountered almost universally in longitudinal incisions over the sternum. There are also, those complications which are incident to

endotracheal anesthesia. Lester[17] has drawn particular attention to postoperative subglottic edema secondary to endotracheal intubation. Protection for the anterior chest wall, following removal of traction apparatus, probably is not a necessity; however, Gross[14] has suggested that a light plaster vest be worn for one month following discharge from the hospital.

The mortality rate is extremely low. Indeed, the recent literature is almost devoid of mention of operative deaths. Lester[17] reported one death in 94 operations; Ravitch[11] reported one death, from massive infection, in 21 operations. By contrast, Ochsner and DeBakey,[3] in their review of the literature in 1939, reported six deaths in 32 operative procedures.

RESULTS

The over-all results of repair for funnel chest are good. In order to consider a result as satisfactory, there should be a correction of better than 75 per cent of the original defect.[17] Possibly the symmetrical deformity offers a better reparative prognosis than the asymmetrical.[14] On occasion, the cosmetic result may not be as satisfactory as the physiologic improvement. Brown and Cook[10] have stated that the "respiratory and psychologic manifestations" usually will be improved; however, the "cardiac" findings are often irreversible and show little change postoperatively even though there may be subjective improvement. The case, presented by Dorner and his associates,[25] with severe cardiac findings, demonstrated an excellent response to operative correction.

The result which is apparent within the immediate postoperative period is a poor index as to the final outcome. During this time, the improvement is usually maximal, diminishes slowly, and finally stabilizes at about the fourth week.[10, 14] Therefore, final evaluation must be deferred until the second or third month, postrepair.

CASE REPORTS

Six cases of pectus excavatum from the thoracic surgery services of the Methodist Hospital of Brooklyn and Kings County Hospital are presented.

TABLE I

CASE NO.	AGE	SEX	CHIEF COMPLAINTS	OTHER ANOMALIES	ELECTROCARDIOGRAM	CARDIAC COMPRESSION
1	6		Deformity	Interventricular septal defect	Right axis deviation	No
2	8		Deformity	None	None	No
3	11		Deformity and dyspnea	None	Left axis deviation; sinus arrhythmia	No
4*	14	M	Deformity and chest pain on exertion	None	Sinus arrhythmia	Yes
5†	14	M	Deformity and mild exertional dyspnea	None	Normal	No
6	2	M	Deformity	None	Sinus arrhythmia	No

*Recurrence of pectus excavatum following former repair.
†Asymmetrical (right) deformity.

All patients were subjected to similar procedures utilizing the new method of sternum stabilization. It is not within the scope of this paper to offer case histories of a control group of patients by more conventional techniques.

The operative procedure followed in 5 cases was the classical "radical" one described by Brown[13] and Lester.[17] A midline incision was performed from the manubriogladiolar junction to just inferior to the tip of the xyphoid process. Muscular attachments to the costal cartilages were separated by sharp dissection. The xyphoid was divided from the gladiolus at the xyphisternal junction. Retrosternal muscular and ligamentous attachments were divided. Segments of all deformed costal cartilages were resected subperichondrially, from the costal arch to as high as the second rib. Transverse anterior cuneiform sternotomy was performed at a level with the highest resected cartilage. The sternum was elevated. A medium-sized Kirschner wire or long Steinmann pin was inserted between the anterior and posterior tables of the gladiolus at a level with the fourth or fifth costal cartilage. The pin was brought out, bilaterally, on the anterior surfaces of the fourth and fifth ribs, penetrating pectoral muscle and skin to emerge just below each nipple. Ordinary corks were threaded on the exposed pin, bilaterally, and the tips bent to prevent the corks from disengaging. Soft gauze was placed beneath the corks to afford protection of soft tissues against pressure effects. Collodion dressings covered the pin puncture sites. Strips of adhesion tape, from cork to cork, added further protection. Soft tissues were approximated in the midline. The anterior fascia of the rectus abdominis was sutured at the site of division from the lowest cartilages. Numerous sutures closed the subcutaneous tissues to provide less tension on the skin sutures in an attempt to avoid or minimize keloid formation. Drainage was utilized in a majority of cases; however, no wound complications were noted in any case. In 2 patients, the pleura was inadvertently entered during surgery with attendant pneumothorax as a complication which was readily controlled by intrapleural catheter closed drainage. The supporting pin was extracted, with minimal discomfort to the patient, on the second to third week postoperatively.

One patient (Case 5) with an asymmetrical deformity was subjected to a different operative procedure from the others. On the more deformed side, double wedge resections of cartilage were removed, modified after Gross.[14] On the other side, small segments were resected. Following transverse sternotomy and elevation of the gladiolus, wire sutures were placed at the sternotomy site and between reapproximated costal cartilages.

TABLE II

CASE NO.	INDICATIONS FOR SURGERY	RIBS RESECTED	PIN EXTRACTED (DAY)	COMPLICATIONS	RESULTS
1	Cosmetic	2 - 7	18	None	Fair*
2	Cosmetic	3 - 7	18	None	Good
3	Cosmetic	2 - 7	14	Pneumothorax	Good
4	Cosmetic	4 - 7	18	Pneumothorax	Good
5	Cosmetic	3 - 7	21	None	Good
6	Cosmetic	3 - 7	18	None	Good

*Resulted in overcorrection giving appearance of mild pigeon breast.

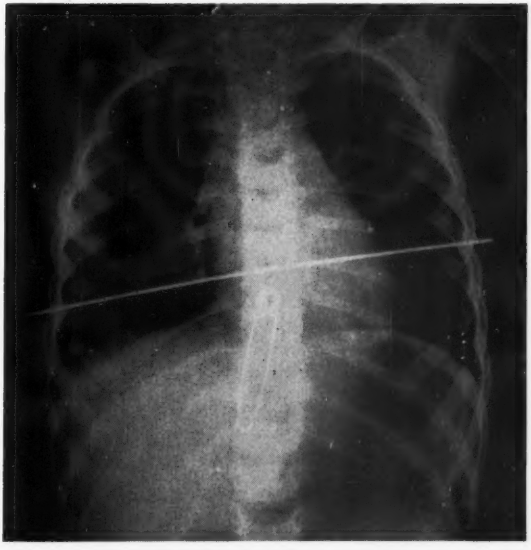

Fig. 1.—Posteroanterior view with pin in situ.

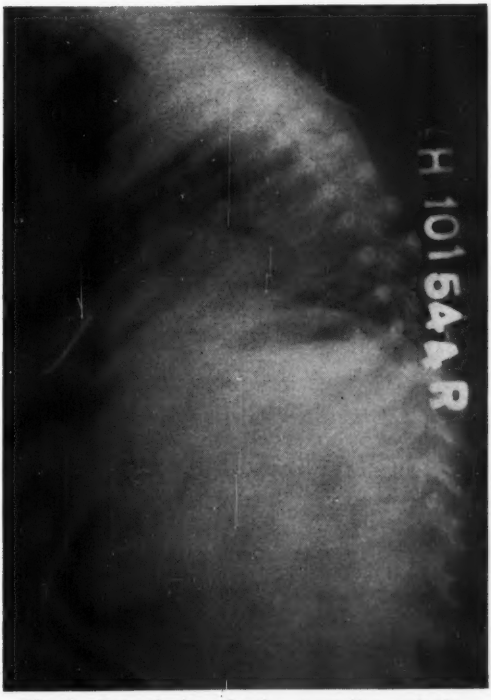

Fig. 2.—Lateral view showing correction and pin.

DISCUSSION

The patients presented varied from 2 to 14 years of age. All gave a history of upper respiratory infections or some form of respiratory distress. Only one patient had pulmonary function tests (Case 5); the significant abnormalities being a vital capacity of 65 per cent of predicted normal and a maximum breathing capacity of 77 per cent of the predicted normal. The electrocardiogram showed right axis deviation in one patient and sinus arrhythmia in 3. The indication for surgery in all patients was primarily

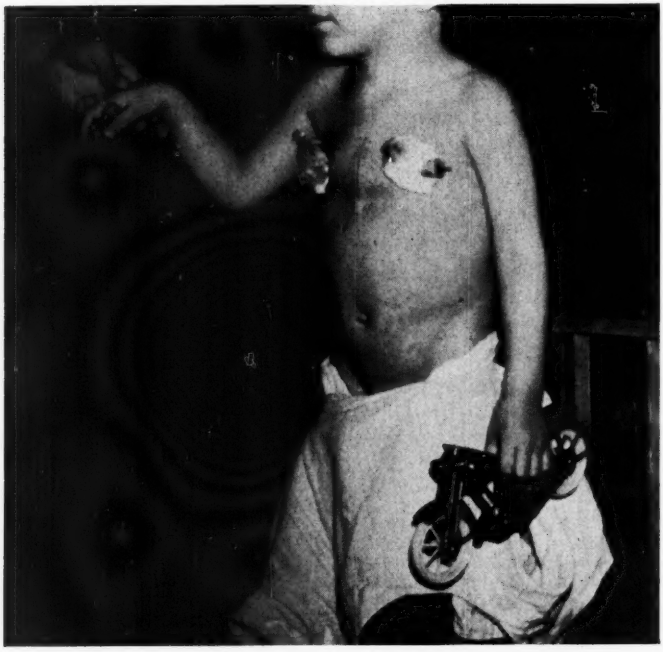

Fig. 3.—The suggested method of maintenance of correction in an ambulatory patient.

"cosmetic." Five of the 6 cases were primary repairs; Case 4 was a patient who had been subjected to corrective surgery three to four years previously and had had a recurrence. Follow-up extends from three months to three years, postoperative. Results are considered "good" in 5 and "fair" in one. The reason for classifying one patient as having only a "fair" result is that the defect was overly corrected; producing, in essence, a mild form of pectus incarnatum.

COMMENT

Maintenance of the elevated gladiolus in a corrected, or overly-corrected position is, in our opinion, inimicable to the success of reparative surgery for pectus excavatum. Wire traction sutures attached to an apparatus applied

to the anterior chest wall[2, 7, 8, 10, 12-14, 17, 18, 22, 34, 39] accomplishes this requisite quite satisfactorily. There are, however, three inherent drawbacks; (1) the suture may break or tear out, (2) the patient must wear a rather cumbersome, though perhaps light, apparatus, and (3) the chest wall appliance may not remain stable. The rib strut method[17, 35, 36] is limited to use in adults. Miscall[38] utilized *crossed* Kirschner wires *retrosternally* for elevation correction of funnel chest in one case. One wire migrated into the pericardium several months postoperatively; however, the costosternal deformity had been successfully treated.

Kirschner wires or Steinmann pins, used as we have described, have the disadvantage of not maintaining overcorrection; if, indeed, this is a disadvantage. Our limited experience does not indicate that overcorrection is necessary. There is no danger of migration of the pin or of trauma to intrathoracic viscera because the pin remains separated from these structures. Danger of infection is no greater than with any other traction mechanism extending to the exterior by penetrating skin. The major advantages are; (1) the pin cannot disengage the sternum, as with wire sutures (assuming that the correct caliber pin is selected), (2) there is no cumbersome external appliance, only two corks, and (3) it is readily inserted without resort to additional incisions, as when rib graft struts are employed.

SUMMARY

1. The etiology and evolution of the surgical treatment of pectus excavatum has been presented.

2. A new method of maintenance of the elevated sternum in corrected position has been described.

3. Six cases of pectus excavatum treated surgically are added to the literature.

4. We believe that no single operative technique is applicable to all patients with this deformity. Each case should be evaluated in the light of which particular procedure will lend itself most advantageously to the deformity at hand; in short, a custom-tailoring procedure.

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THE SURGICAL MANAGEMENT OF LARGE INTRATHORACIC GOITERS: CONTRIBUTIONS OF ANGIOCARDIOGRAPHY

LAURENCE MISCALL, M.D., RICHARD B. NOLAN, M.D., NATHANIEL FINBY, M.D., AND ISRAEL STEINBERG, M.D.
NEW YORK, N. Y.

LARGE tumors of thyroid origin are seen frequently in the superior mediastinum. Prompt surgical excision is indicated because of progressive symptoms due to displacement or obstruction of adjacent vital structures and the increasing difficulties inherent in delay. The reports of incomplete operation, postoperative hemorrhage, and infection with the use of the usual collar incision have been common enough to indicate that greater success may be achieved by the additional use of some type of thoracic incision. Experience has shown that this is not only safer in many cases but also indispensable in others. Furthermore, the very extensive use of tomography and angiocardiography at the New York Hospital demonstrates that these methods as supplements to other routine roentgenographic studies often yield information useful in the better adaptation of the operative approach to the anatomic situation of the tumor. These studies of 5 patients with very large thoracic thyroid tumors were selected to show how thorough roentgenographic study, especially angiocardiography, aided in planning a suitable surgical approach.

CASE REPORTS*

CASE 1.—A 32-year-old man was admitted to the hospital because an asymptomatic superior mediastinal mass had been found on a survey chest x-ray. It was barely palpable in the supraclavicular space. The basal metabolic rate was -21 and other laboratory findings normal. On chest roentgenograms (Fig. 1, *A* and *B*), a large right superior mediastinal mass extended inferiorly to the right upper lobe bronchus and displaced the trachea and esophagus to the left. Angiocardiography showed that the tumor also displaced the innominate artery and right brachiocephalic vessels to a right anterolateral position (Fig. 1, *C* and *D*). A right anterior transthoracic approach combined with the usual cervical collar incision was selected.

Operation.—On Feb. 16, 1949, the neck was explored through a low collar incision. Since the tumor could not be safely mobilized through this approach, the right thorax was opened anteriorly through the bed of the third rib. After incision of the mediastinal pleura, the tumor was freed without difficulty. With careful manipulation in both the chest and neck and with anterior retraction of the great vessels, the tumor was delivered through the thoracic inlet. A thin stalk connected it to the right thyroid lobe and after division and ligation of the superior thyroid vessels, the mass and right lobe were excised. The chest and neck were both drained and the wounds closed without repair of the mediastinal pleura.

Pathologic Diagnosis.—Nodular thyroid with involution and cystic degeneration.

From the Private Patient Surgical Service and the Department of Radiology, New York Hospital-Cornell Medical Center and Triboro Hospital, New York, N. Y.

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*General anesthesia, administered by endotracheal technique, was employed in all patients.

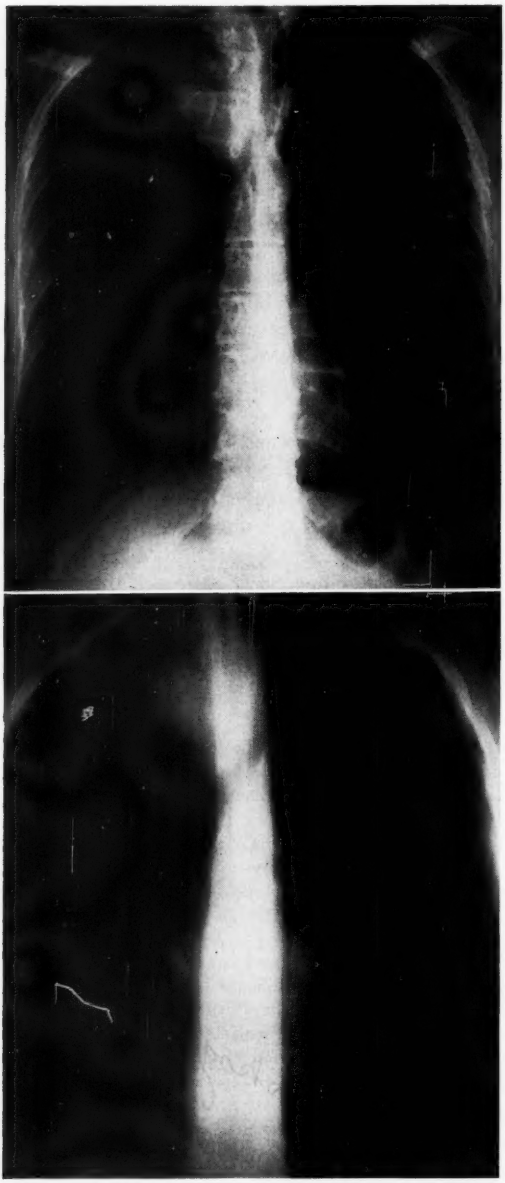
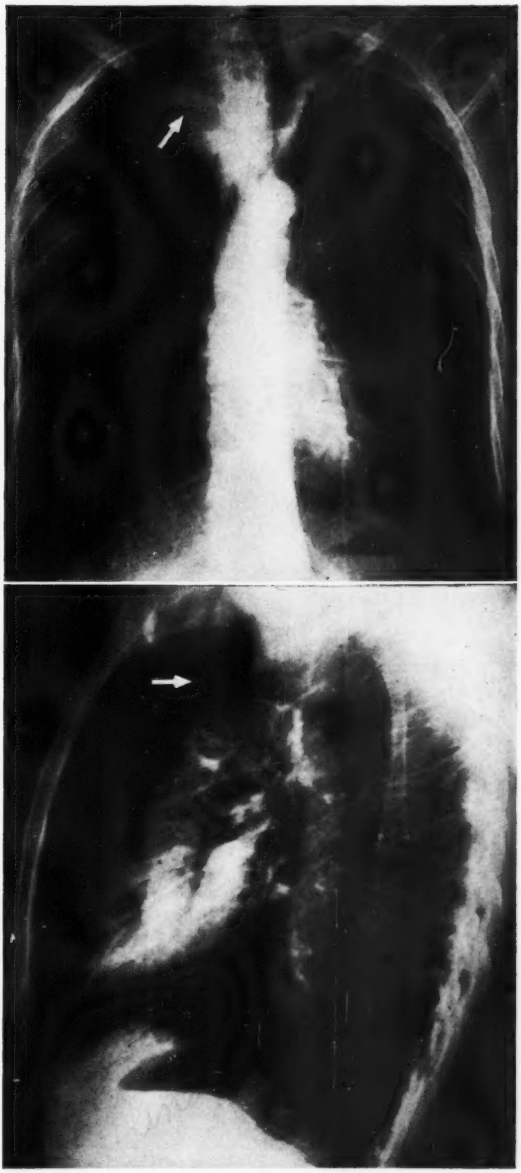


Fig. 1.—Case 1. *A*, Frontal chest x-ray shows a large right superior mediastinal tumor displacing the trachea to the right. *B*, Frontal tomogram demonstrates that the mass extends deep into the region of origin of the right bronchus, the trachea is not narrowed; the cartilaginous rings are intact.

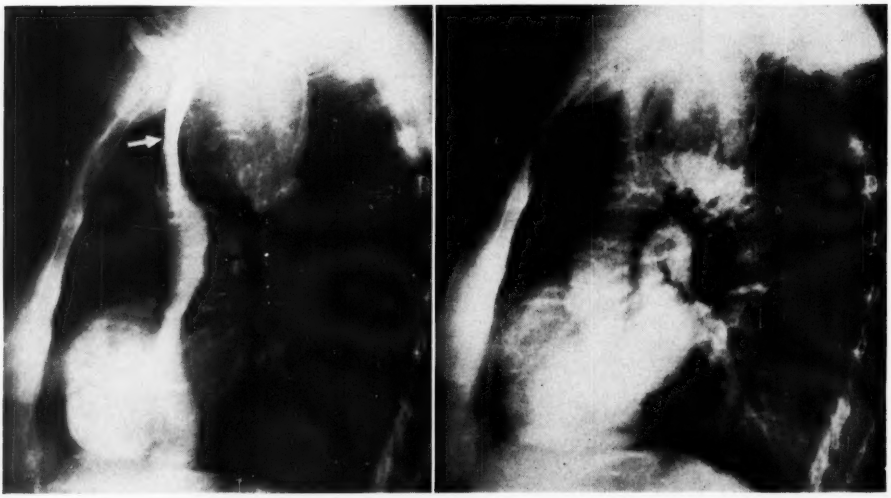


C.

D.

Fig. 1 (Cont'd).—*C,* Frontal angiocardiogram demonstrates the opacified left ventricle, aorta, and brachiocephalic branches. Note that the tumor lies between the displaced trachea and innominate artery (arrow). *D,* Lateral angiocardiogram also reveals the opacified left cardiac chambers and aorta. Note the forward displacement of the innominate artery (arrow).

A.



B. *C.*

Fig. 2.—Case 2. *A*, Frontal angiocardiogram shows the opacified left heart and aorta; a huge goiter lies behind the trachea and is displacing the distal part of the innominate artery. *B*, Lateral angiocardiogram shows forward displacement of the right innominate vein (arrow); the tumor extends deep within the mediastinum and is behind the trachea. *C*, Lateral angiocardiogram shows the opacified left heart chambers and aorta. Note the displacement of the brachiocephalic vessels.

CASE 2.—The patient, a 45-year-old housewife, had had an enlarged thyroid gland for several years. Six months prior to admission she had noted progressively frequent and severe "smothering attacks." An enlarged nodular thyroid gland was present. The chest roentgenograms showed a huge right superior mediastinal mass extending posterior to the trachea and the esophagus, displacing them into the left hemithorax. Angiocardiography showed marked anterior and right lateral displacement of the right brachiocephalic vessels (Figs. 2 *A*, *B*, and *C*). In view of its size and intimate relation to the posterior mediastinal structures, a right thoracic approach combined with a collar incision was selected.

Operative Findings.—On Feb. 7, 1955, using a submammary incision, the right thorax was opened through the bed of the second rib. The tumor displaced the great vessels anteriorly and to the right, and extended from the right upper lobe bronchus to the thoracic inlet. It extended anteriorly and posteriorly around the trachea and esophagus. The pleura was incised and, following mobilization of the great vessels anteriorly, the tumor was separated from the bronchus and trachea. Traction on the tumor delivered the esophagus which was then freed under direct vision. Ligation of many small vessels was necessary. The size of this thoracic tumor would not permit passage into the neck and accordingly most of it was excised. Further dissection through a low collar incision permitted the remainder to be delivered into the neck and removed. The wounds were closed with drainage of the right chest only.

Pathologic Diagnosis.—Nodular cystic goiter with involution.

CASE 3.—A 64-year-old housewife was admitted to the hospital with complaints of chest pain, dyspnea, and hoarseness of four months' duration. Through a cervical incision, a previous attempt at subtotal thyroidectomy had been unsuccessful. Roentgenography with tomography revealed a large righ superior mediastinal mass which extended retrosternally and yet the esophagus and trachea were displaced toward the right (Fig. 3, *A*). Angiocardiography (Fig. 3, *B* and *C*) showed a compressed right innominate vein, right posterior displacement of the innominate artery, and displacement of the left brachiocephalic vessels to the left. The need for exposure of both sides of the trachea in the area between the great vessels was evident and therefore a sternal splitting incision in combination with a low collar incision was selected.

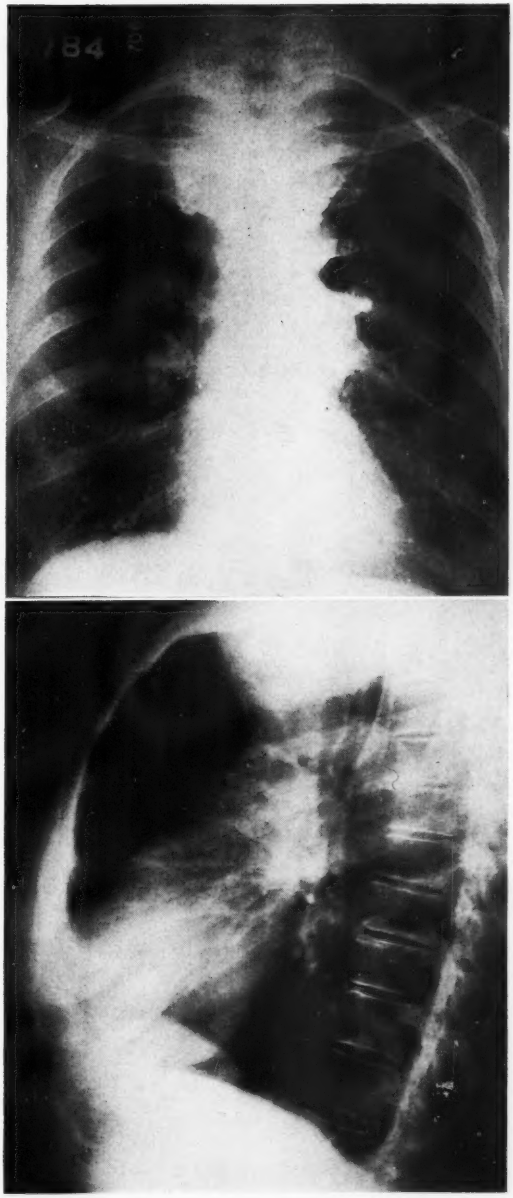
Operation.—On Feb. 28, 1955, the sternum was split from notch to xiphoid. The substernal portion of the tumor filled the mediastinum, extending inferiorly over the pericardium, displacing the superior vena cava anteriorly and to the right, and the innominate artery and branches posteriorly and to the right. The superior vena cava and innominate veins were mobilized, the left being compressed and barely visible on the anterior surface of the tumor. It was then possible to dissect the aorta and trachea free from the posterior surface. The connection of the tumor mass to the left thyroid lobe was divided and the mass excised. The trachea and esophagus were still markedly displaced to the right by a second mass lying posterior to the axis of the aortic arch and left brachiocephalic vessels. With retraction of these vessels to the left and inferiorly, this mass was mobilized to the thoracic inlet where it also was connected to the left thyroid lobe. Dissection in both the mediastinum and neck permitted the tumor to be delivered through a collar incision into the neck and excised with the left thyroid lobe. Both pleural spaces were drained.

Pathologic Diagnosis.—Nodular goiter with cystic degeneration and involution.

CASE 4.—The patient, a 64-year-old housewife, complained of increasing cough, hoarseness, dyspnea, and headache for six months. The thyroid was nodular and symmetrically enlarged and engorged veins of the neck failed to empty normally. The chest roentgenograms (Fig. 4, *A* and *B*) revealed a massive superior mediastinal tumor, containing multiple amorphous calcific densities, which extended into the neck. The midline trachea was markedly and concentrically narrowed at the thoracic inlet productive of a "crowing" respiration. On

A. *B.* *C.*

Fig. 3.—Case 3. *A*, Frontal tomogram demonstrates marked bowing of the trachea to the right by a huge goiter. *B*, Lateral angiocardiogram shows compression of the right innominate vein (arrow). *C*, Frontal angiocardiogram reveals opacification of the left heart and aorta. The right innominate artery (arrow) is markedly displaced by the goiter.



A.

B.

Fig. 4.—Case 4. *A*, Frontal chest x-ray reveals a massive superior mediastinal mass. *B*, Lateral x-ray shows that the mass surrounds and compresses the trachea and contains calcific deposits.

C.

D.

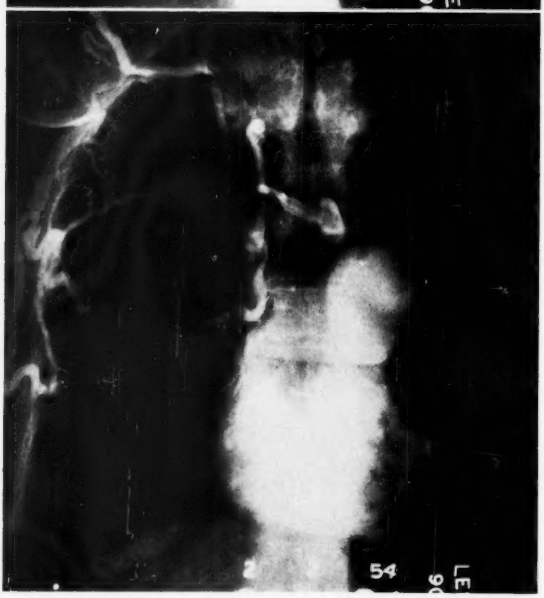


Fig. 4. (Cont'd).—*C*, Frontal angiocardiogram reveals narrowing of the right innominate vein, causing collaterals. Note the markedly narrowed trachea. *D*, Frontal angiocardiogram at a later time reveals collaterals entering the vena azygos system.

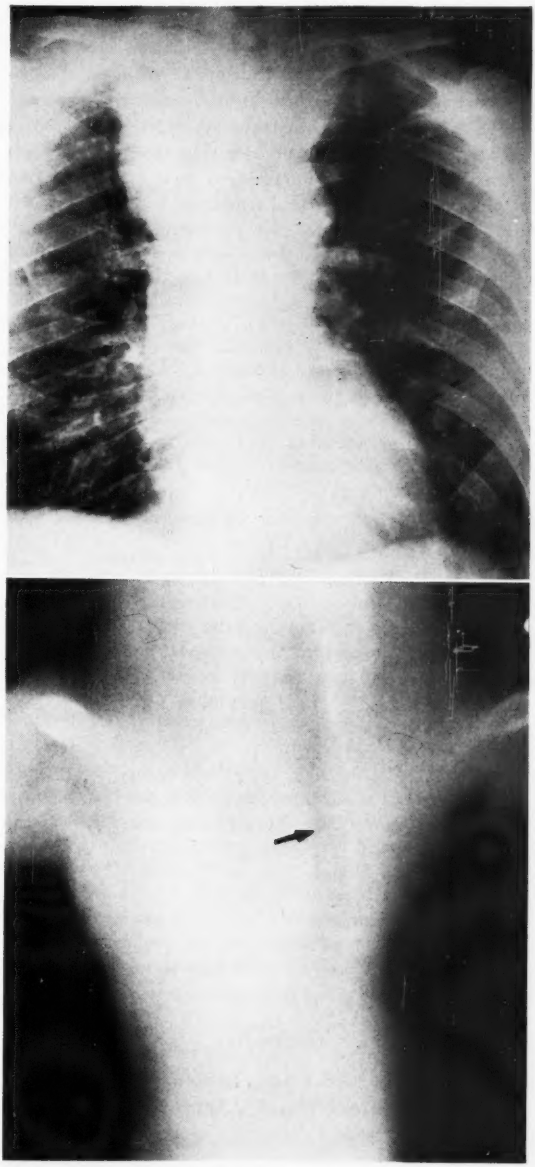


Fig. 5.—Case 5. *A*, Frontal chest x-ray shows a huge goiter deviating the trachea toward the left. *B*, Tomogram reveals loss of the cartilaginous rings on the right (arrow).

angiocardiography (Fig. 4, *C* and *D*), the right innominate vein was narrowed sufficiently to produce collateral circulation through the azygos system. The pulmonary artery and branches were moderately enlarged and the brachiocephalic vessels of both sides were displaced laterally. Tomography failed to reveal any cartilaginous rings. A primary collar incision, supplemented by a sternal splitting incision, was selected with the hope of avoiding opening the pleural spaces in the presence of tracheal compression requiring tracheotomy.

Operation.—On Feb. 5, 1954, the thyroid was exposed through a collar incision. Since removal required further exposure, the sternum was split to the level of the fourth rib. By spreading the sternum and converting both incisions to a large, triangular area, excellent visualization was obtained. After both pleural reflections were mobilized with special care to avoid opening either pleural space, the inferior portion of the tumor was raised from the aorta. Its size and the transverse course of the left innominate vein prevented block excision. The mass then was mobilized from the anterior surface of the trachea and split longitudinally into two parts, carefully avoiding injury to the left innominate vein. Each half was then mobilized from below upward and, after ligation of many vessels, excised separately. The compressed section of trachea did not have its normal cartilaginous support and partial withdrawal of the endotracheal tube was followed by tracheal collapse and inspiratory stridor. The tube was advanced for support while a tracheotomy was performed through which a long endotracheal tube permitted continuation of anesthesia and maintained an excellent postoperative airway for ten days. The cervical portion of the trachea was supported by bilateral suturing to the medial border of the sternocleidomastoid muscles. The wounds were closed, and drainage was employed for twenty-four hours.

Pathologic Diagnosis.—Nodular goiter with cystic degeneration and involution.

CASE 5.—The patient, a 61-year-old white man, complained of mild intermittent dysphagia and choking sensations. Distended neck and chest veins and an enlarged nodular thyroid were the significant physical findings. Chest roentgenograms (Fig. 5, *A*) showed a large right superior mediastinal mass displacing the trachea to the left but not seriously compressing it. Tomography showed that this displacement was accompanied by lateral compression and loss of the cartilaginous rings on the side of the tumor, as contrasted with normal rings on the opposite side. Angiocardiography demonstrated abundant collateral circulation due to obstruction of the superior vena cava. A right thoracic incision combined with the low collar incision was selected.

Operation.—On Dec. 22, 1955, the right thorax was opened through the bed of the right anterior third rib. The mass extended from the right upper lobe bronchus to the thoracic inlet and displaced the trachea to the left. Through an incision in the mediastinal pleura, it was mobilized from the trachea and esophagus posteriorly after the great vessels had been freed and retracted anteriorly. Despite this mobilization, the tumor could not be delivered into the cervical incision even after division of the strap muscles including the sternal head of the right sternocleidomastoid. Following excision of its major portion within the thorax, delivery and excision in the neck were readily accomplished. The wounds were closed with drainage of the right chest without repair of the mediastinal pleura.

Pathologic Diagnosis.—Nodular goiter with marked cystic degeneration.

DISCUSSION

Mediastinal tumors of thyroid origin are not uniform in size, location, or mode of connection to the parent gland. An accurate knowledge of the relationship of these thoracic goiters to the great vessels, trachea, and the esophagus provides the best basis for the most suitable surgical approach. These cases were specifically selected because they demonstrate great variation in detailed findings which cast doubt on the contention that all can be safely removed through the cervical approach.

The size of the mediastinal component alone is often sufficient to contraindicate the attempt to excise it through an exclusively cervical approach. The difficulties in Cases 2, 3, 4, and 5, in which preliminary thoracic excision was necessary, amply support this belief. Furthermore, careful study of the relationships of these tumors to surrounding structures should arouse some suspicion as to the acceptability of blind dissection in the neighborhood of such structures as both pleural spaces, the great vessels, the esophagus, and the trachea. Unless one is prepared to trust to luck in the presence of uncontrolled vascular tributaries, thoracic exposure must be obtained at least in some instances.

In addition to these general objections, our experience further indicates that more careful evaluation, particularly by tomography and angiocardiography, permits classification sufficient to clarify the mode and time of departure from uniform cervical approach.

I. Superior mediastinal goiters, which displace the trachea and esophagus to the left, present predominantly in the right superior mediastinum and displace the right great vessels anteriorly and to the right. Any substernal portion may compress the left innominate vein. These tumors more often displace than concentrically compress the trachea. A combination of cervical and right transthoracic incisions has provided excellent exposure under such circumstances (Cases 1, 2, and 5). With adequate opening of the mediastinal pleura, the vessels have been readily freed and retracted anteriorly. This has permitted, under direct vision, mobilization of the tumor from the lateral aspect of the bronchus and trachea and particularly, as in Case 2, from the esophagus. Manipulation in both the neck and thorax has permitted passing the thoracic portion into the cervical area and then excising it en masse with the right lobe. It also has been possible when necessary, as in Cases 2, 3, and 5, to excise the thoracic portion thus allowing the remainder to be delivered into the neck and removed with the attached thyroid gland. The excellent visualization of the posterior superior mediastinum and the lesser risk of opening both pleural spaces make this approach preferable to the sternal splitting incision which, however, may also be used.

II. Superior mediastinal goiters which displace the trachea and esophagus to the right expand from a position posterior to and on the right of the axis of the aortic arch and the left great vessels. These split the great vessels of the two sides in opposite directions. They may cross the midline. Thus, in Case 3, the left brachiocephalic vessels were displaced to the left while the substernal and right portions of the tumor compressed and displaced the right innominate vein and superior vena cava to the right and anteriorly, but the innominate artery posteriorly. It should be noted that previous substernal thyroidectomy, through an exclusively cervical incision, had been unsuccessful. Such an unusually large and lobulated tumor should be approached between the great vessels of both sides in order to expose both sides of the trachea. Under such circumstances, a combination of low collar and sternal splitting incisions has proved very satisfactory. Careful inspection of the

operative details of this case shows that the position of the great vessels over the face of the tumor made right and left thoracic approach undesirable. In contrast to Case 4, both pleural spaces were opened and drained without fear since tracheotomy was not anticipated in this patient. Again, the low collar incision has provided for ready delivery and excision of the remaining portion of the thyroid. Thoracic drainage alone has proved sufficient.

III. Superior mediastinal goiters which surround the trachea often severely compress it in a concentric manner without significant displacement and usually at or just below the thoracic inlet. The serious encroachment on the airway is also complicated by an extensive loss of normal cartilaginous support over the entire circumference in the area involved. Such findings require caution since an incompetent airway may result from removal of the supporting structure of the thyroid gland unless maintained through tracheotomy and other measures as in Case 4. This contrasts with the findings in the other cases in which, although tracheal displacement has been accompanied by some deformity and softening on the side of pressure, the patency has been uniformly maintained by the undisturbed cartilaginous support in the remaining circumference making tracheotomy unnecessary. Tomographic survey of the tracheal rings in the tumor area has been a very satisfactory method of demonstrating such changes. The contrast is well illustrated by comparison of the x-rays of Case 4 with the others, particularly Case 5. The probable necessity for tracheotomy has rendered removal without pleural opening very desirable since a sucking wound with a leaking tracheotomy may carry serious hazard of pleural complications. Under these circumstances, a low collar incision with partial or complete splitting of the sternum has provided satisfactory exposure with maximal control of the airway and pleural problems. If one or both pleural spaces are accidentally opened, both anterior and posterior thoracic tube drainage should be instituted.

SUMMARY

1. In some patients with intrathoracic tumors of thyroid origin, the additional exposure gained by thoracic incision, supplementing the usual cervical incision, decreases the difficulties and risks of operation through the cervical approach alone. Such a combined approach is particularly useful for extremely large tumors with complex relationships to surrounding vital structures.

2. Tracheotomy is usually unnecessary when the trachea is simply displaced but, with concentric compression and loss of support by the cartilaginous rings, it is an indicated routine. Under such circumstances, exposure should be planned with the hope of avoiding the opening of the pleural spaces.

3. The most suitable approach can be planned with information gained when tomography and angiocardiography are combined with the routine studies in defining the anatomic relationships.

4. Five cases have been reported to illustrate the details of the diagnostic and therapeutic planning.

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THORACIC MENINGOCELE ASSOCIATED WITH NEUROFIBROMATOSIS

ERIC M. NANSON, F.R.C.S.
SASKATCHEWAN, CANADA

SINCE 1933, sporadic cases of thoracic meningocele have been reported in the literature. Over the last ten years an increasing awareness of the condition has been apparent. The notable feature of the majority of the recorded cases is that the patients have been suffering from neurofibromatosis and that they have had a kyphoscoliosis of the thoracic spine. Therefore, this may be considered to constitute a syndrome, i.e., generalized neurofibromatosis, kyphoscoliosis, and intrathoracic meningocele.

The purpose of this communication is to report a further example of this syndrome, in which the intrathoracic meningocele was successfully treated by surgery. Furthermore, the present example appears to be the largest one so far reported.

CASE REPORT

The patient, Mrs. E. E., was a 34-year-old white housewife. In early life café-au-lait spots were noted on the skin. When about 16 years of age, the patient first noticed the appearance of soft lumps scattered diffusely over the skin. These gradually increased in size and number. Three years before, at the age of 31 years, she fell hard onto her buttocks and this resulted in paralysis and anesthesia from the waist down. She also had temporary incontinence of feces and urine. One month later she had regained the use of her legs and sensation had returned to the right leg but complete return of sensation did not occur in the left leg. At this time a marked kyphoscoliosis had developed; she denies its presence before the age of 31 years, three years before. An x-ray of the lung fields revealed a large shadow in the right hemithorax (Fig. 1). In June, 1953, two years before, she had had a spinal fusion performed in the region T_1-T_8 to prevent further kyphoscoliosis and the danger of further cord damage. Since that time she had been unable to work because of lack of energy and pain in the back. She also noticed she had become short of breath on moderate exertion.

On admission to the University Hospital, her complaints were pain in the back, shortness of breath on exertion, lack of energy, marked bowing of the back, and a degree of hypoesthesia of the left leg, left half of abdomen, and back below the umbilicus, and some weakness of muscle action of the left leg.

Examination showed a small, thin woman with a webbed neck and a marked kyphosis of the cervicothoracic spine. There were numerous soft papillomatous lesions of neurofibromatosis over the whole skin associated with café-au-lait spots (Fig. 2). The chest had poor expansion and was dull to percussion over the right upper chest. Air entry was absent in this area.

There was slight weakness of all muscle groups of the left leg with diminution of sensation to light touch, pin prick, and vibration sense throughout the entire left leg up to the iliac crest.

From the Department of Surgery, University of Saskatchewan, Canada.
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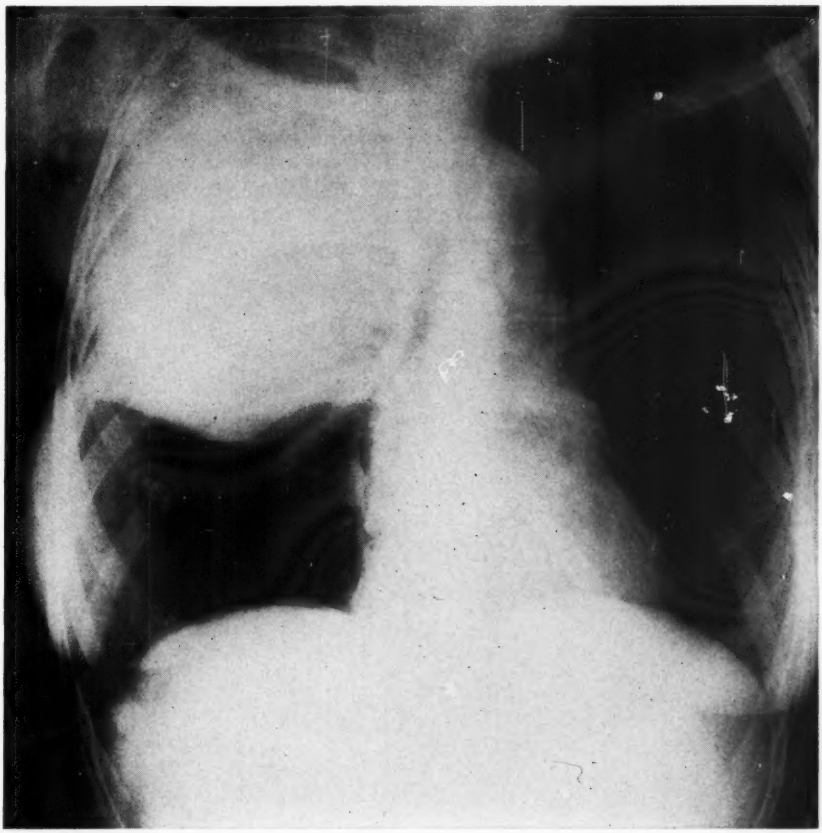

Fig. 1.—Anteroposterior x-ray of chest taken April, 1953, 2½ years before operation.

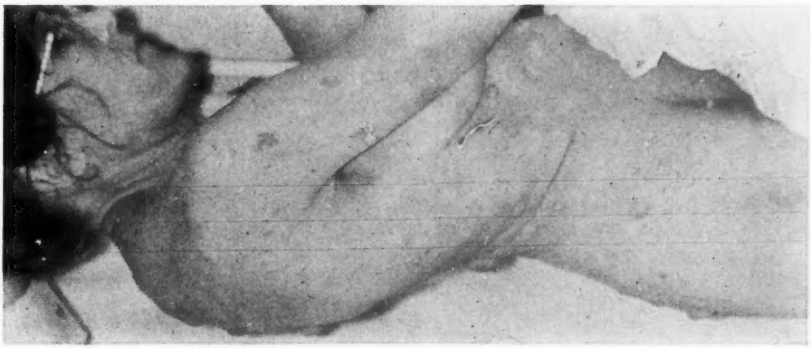

Fig. 2.—Shows marked kyphosis and stigmata of von Recklinghausen's disease.

X-ray of the lung fields was reported by Dr. E. W. Spencer as follows: "Postero-anterior and lateral views of the chest show the presence of a tremendous mass occupying a greater portion of the right hemi-thorax, and in lateral projection this seems to lie primarily in the middle of the posterior mediastinum." (Fig. 3.) X-ray of the thoracic spine showed a gross kyphoscoliosis of such a degree that, in the anteroposterior projection, a direct view was obtained along the lumen of the upper thoracic vertebral canal. The apex of the kyphosis appeared to be at the level of the fourth thoracic vertebra. No obvious enlargement of the intervertebral foramina could be demonstrated radiologically.

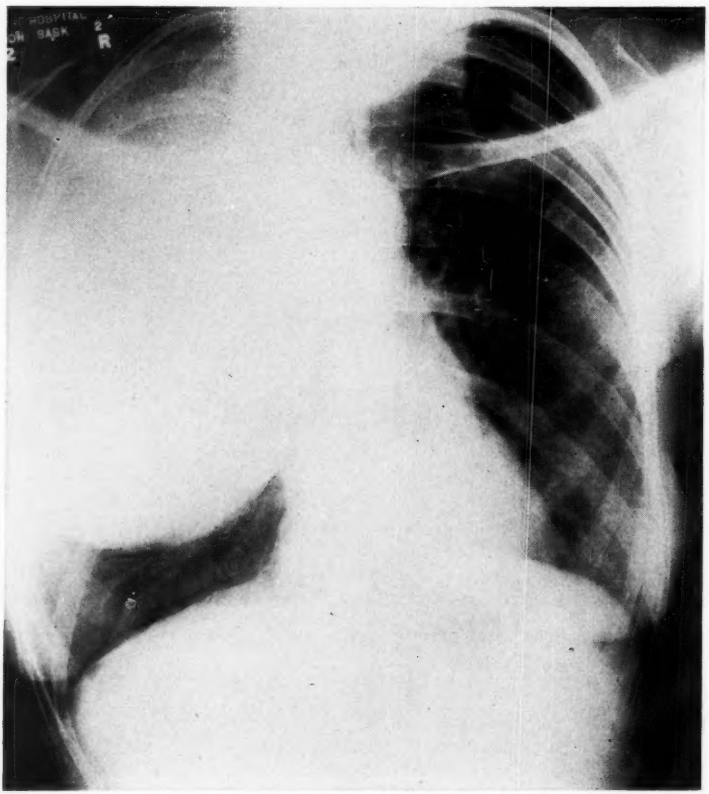

Fig. 3.—Posteroanterior x-ray of chest showing huge meningocele on right side. September, 1955—taken 2 weeks before operation.

Ventilatory function was evaluated by Dr. J. E. Merriman. The vital capacity was 58 per cent of normal. The maximum breathing capacity was 76 per cent of normal.

The preoperative diagnosis was a large neurofibroma occupying the right chest.

Accordingly, on Sept. 8, 1955, I performed a right lateral thoracotomy. The anesthetist was Dr. Gordon M. Wyant.

The right chest was largely occupied by a large, smooth, thick-walled cyst containing clear brown-tinged fluid (Fig. 4). The cyst was attached in the paravertebral gutter in the region of the fourth thoracic vertebra at the apex of the acute kyphosis. The cyst was entered and dissected free to its neck, which was divided at the level of the intervertebral foramen.

When this was done, clear fluid was seen to pulsate out of the neck with every heart beat, and the index finger could be passed through the neck into the vertebral canal. The fluid was deduced to be cerebrospinal fluid, although the spinal cord was not visualized. The neck of the sac was closed with interrupted No. 4-0 silk sutures so that no further leak occurred. After the removal of the cyst, the lung was able to be expanded to fill about three quarters of the chest cavity. Accordingly, a catheter was inserted into the chest and the chest closed in routine manner. The catheter was connected to underwater-seal drainage.

Three days later the lung had expanded well, but 400 c.c. of blood-tinged fluid was aspirated from the chest. Four days after the operation, the patient complained of marked pain down the ventral aspect of both thighs and weakness of the right leg. Straight leg raising of the right leg was limited to 20 degrees by pain in the front of the right thigh. Patella and ankle clonus were present on the right. There was a right Babinski response. There were no sensory changes.

Fig. 4.—Appearance of meningocele at operation.

Eight days after operation she was seen by Dr. Alan Bailey for neurologic assessment and he reported a partial Brown-Séquard syndrome with a lesion high in the thoracic area.

A lumbar puncture done on the sixth postoperative day gave xanthochromic fluid with 520 mg. of protein per cubic centimeter, so that Dr. Bailey suggested that there had been some hemorrhage into the cord at the site of the operative removal of the meningocele.

The patient made a slow but steady recovery with the return to her preoperative condition as regards her neurologic status. The ventilatory function studies were repeated seventeen days after operation. These showed a definite improvement of ventilatory capacity. The lung had fully expanded (Fig. 5).

The Pathological Report (Dr. D. F. Moore).—A collapsed saclike structure was seen. One pole was open. It measured 15 cm. in length and had a maximum circumference of 21 cm. Adjacent to the opened end, the wall was pale pink in color, averaging 0.2 cm. in thickness. At the opposite end, the tissue became whitish gray and almost gelatinous in consistency with the thickness increased to 2.6 cm. Externally this sac was fairly smooth; internally it had a wrinkled, leathery appearance.

Histologically, the cavity was lined by pale amorphous eosinophilic material, sometimes laid down in vague lamellae. In the region of the surgical opening, vestiges of leptomeninges were found. These were undergoing bland degeneration and patchy calcification.

The bulk of the edematous wall was composed of loosely arranged, elongated cells with medium-sized fusiform nuclei. These cells seemed identical to those noted in the subcutaneous neurofibroma excised at the same time. This portion was well vascularized. It was encased in fibrotic parietal pleura, overlying peripheral nerve fibers. Near the neck of the sac, a few ganglion cells were incorporated in the nerves (Figs. 6 and 7).

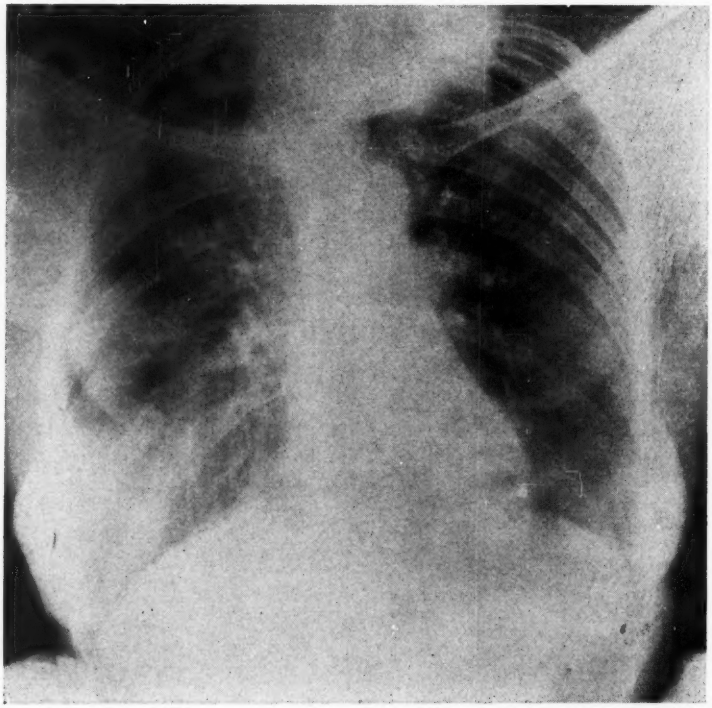

Fig. 5.—Chest x-ray after excision of meningocele showing complete re-expansion of lung.

DISCUSSION

As in previously reported cases, the diagnosis was not suspected until operation. The excuse for this is that the syndrome was not then known to the author. The patient had suffered from the manifestations of von Recklinghausen's disease since early life. Five years before she was seen at the University Hospital, she had had a tuberculosis survey film of the chest taken and this had showed the mass in the right hemithorax. Then, in 1953, she had fallen on her buttocks and had sustained cord damage. Both she and her mother state that the kyphoscoliosis had not been present before this time, but it is hard to accept this as fact. Chest x-ray at that time showed the mass in the right hemithorax to occupy about two thirds of the right lung field (Fig. 1).

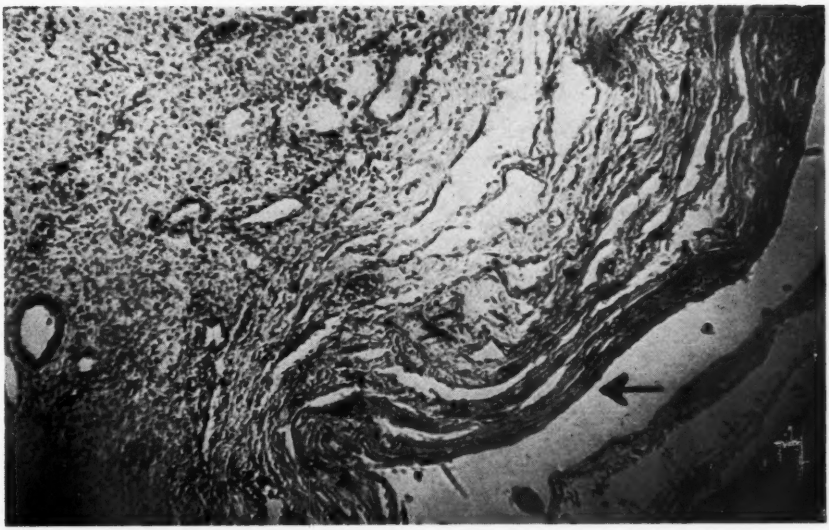

Fig. 6.—Microscopic slide of the wall of thoracic meningocele showing the meninges (arrow) and also the tissue typical of a neurofibroma. (Low power.)

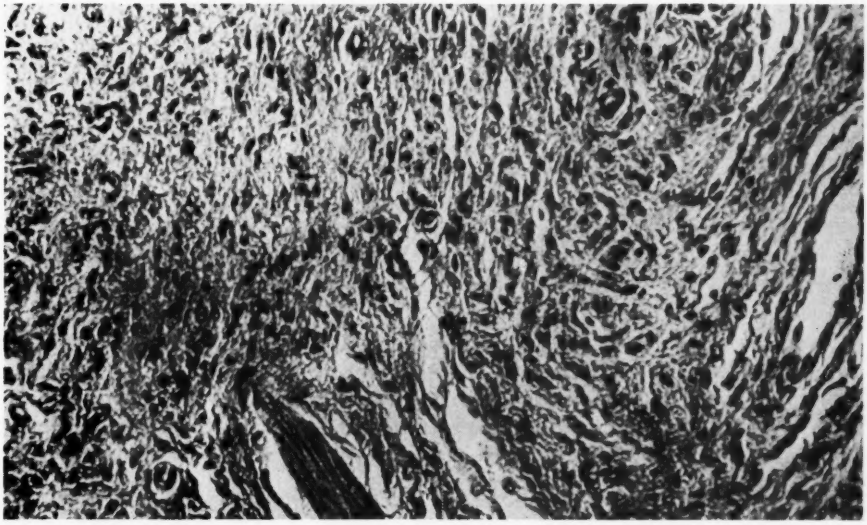

Fig. 7.—Microscopic section of subcutaneous neurofibroma which is exactly similar to the tissue in the wall of the meningocele. (High power.)

Some progression of the size of the mass had occurred over the succeeding three years and progressive shortness of breath had occurred. This was relieved by excision of the cyst and re-expansion of the right lung. Following operation some further temporary cord damage occurred.

The danger of removal of these intrathoracic meningoceles has been shown by other writers. Mendelsohn and Kay[1] (1949) go so far as to say that they doubt the advisability of operating on these patients unless their symptoms are progressive.

The first recorded case in the literature is that of Pohl[2] (1933). He operated on a 47-year-old woman with neurofibromatosis, kyphoscoliosis, and a thoracic meningocele on the right side, but the patient died of empyema. In 1938, Schüller and Uiberall[3] recorded the case of a man 56 years of age, who had neurofibromatosis plus a thoracic meningocele, who died following nerve root section of T_6-T_8 for pain. The meningocele was demonstrated by myelography and confirmed at autopsy.

Ameuille, Wilmoth, and Kudelski[4] recorded a case of a 48-year-old woman, in 1940, in whom the meningocele was situated at the level of T_8-T_9. She died of empyema following an operation which had been performed because of the preoperative diagnosis of hydatid cyst.

Cabello-Campos[5] (1946) records the cases of 2 patients diagnosed without confirmation. Segnpiel, Ruzicka, and Lodmell,[6] in 1947, reported a thoracic meningocele on the right side in a 21-year-old soldier. Operation was undertaken, but aspiration of the cyst only was done and the diagnosis subsequently confirmed by myelography. This case was subsequently reported again by Byron and his associates,[7] in 1949.

In 1948, Welch, Ettinger, and Hecht[8] recorded the case of a 41-year-old woman with a neurofibromatosis, marked kyphoscoliosis, and a posterior sulcus tumor at the level of T_6-T_7 with enlargement of the intervertebral foramen. The lesion was a meningocele successfully removed by operation.

Mendelsohn and Kay[1] in 1949, recorded the case of a 40-year-old woman with neurofibromatosis and meningocele, 3 cm. by 4 cm. by 8 cm., in the right chest which communicated with the subarachnoid space through the seventh intervertebral foramen. After excision, a moderate degree of headache and backache persisted for several weeks.

In the same year Byron, Alling, and Samson[7] recorded 2 new cases. A 36-year-old woman, with a known 10-year history of the lesion at the right apex involving the intervertebral foramen between T_2-T_3 vertebrae. Nine years later, there was a large lesion occupying the right upper chest, causing dyspnea. She had a marked scoliosis. The lesion was successfully removed. The second case was a 61-year-old man with neurofibromatosis and kyphoscoliosis. The cyst was 7 cm. in diameter and occupied the right apex of the chest. The patient died at operation of hemorrhage and cardiac arrest.

In the discussion on Byron's[7] paper, Head spoke of a 48-year-old man who had a meningocele diagnosed by lumbar puncture. Aspiration of the cyst revealed exactly similar fluid samples. Cross, Reavis, and Saunders,[9]

in 1949, reported the case of 22-year-old soldier with neurofibromatosis who suffered a spine injury by being blown out of a tank. Three years later, because of pain, he was investigated and seen to have a kyphoscoliosis at the level T_8-T_{10}. At this level, there was a meningocele on the right side. The diagnosis was proved by myelography. The treatment was conservative.

Otani,[10] in 1951, made a diagnosis of intrathoracic meningocele in a 40-year-old woman, by means of direct puncture of the cyst. By percutaneous puncture, he aspirated clear fluid which, by analysis, he showed to be exactly similar in composition to the cerebrospinal fluid.

In 1951, Kessel[11] reported 2 cases. The first was a 23-year-old woman with a marked kyphoscoliosis and a meningocele situated at T_5-T_6, eroding the pedicles of three vertebrae on the left side. It was successfully removed. The second case was in an 8-year-old girl who, at 3 years of age, had an acute mid-dorsal scoliosis. At the age of 7 years she suffered a fall. The scoliosis became worse and the left leg became spastic—then both legs became spastic. She had developed an acute kyphoscoliosis. X-ray showed gross lateral displacement of T_7-T_8 vertebrae. The meningocele was 3 cm. by 2.5 cm.

Kessel[11] states that up to that time 8 cases were recorded in the literature and his 2 made a total of 10, but of these 10, 7 were associated with von Recklinghausen's disease.

In 1952, Ciaglia[12] reported the case of a 31-year-old woman with neurofibromatosis and acute kyphoscoliosis at C_7-T_1 level, who had a meningocele at the left apex of the chest which contained 200 c.c. of fluid. It was successfully removed and the patient was well three and one-half years later.

Rubin and Stratemeier[13] record the youngest patient in the series. In 1952, an infant, aged 7 weeks, was admitted to the hospital because of a progressive respiratory distress due to an anterior thoracic meningocele displacing the trachea and esophagus to the left. There were multiple vertebral abnormalities. Unfortunately, the child died before treatment could be instituted and the defect was found to be at the fourth thoracic vertebral level.

In the Swedish literature, in 1952, Turunen[14] reported the case of a man, aged 33 years, with neurofibromatosis and kyphoscoliosis. He had a meningocele, 4 cm. in diameter, at the level of the T_4-T_5 on the left side. Preoperatively it was thought to be a neurofibroma. It was successfully removed by Nylander.

Cmyral,[15] in 1952, reported the first case of bilateral thoracic meningocele in a man of 53 years of age. This patient had a scoliosis but no mention is made of neurofibromatosis. The diagnosis was proved by injection of Lipiodol into the cyst. No definite treatment was given.

In 1953, Baker and Curtis[16] gave the most comprehensive review of the subject to date and recorded 2 cases. The first was a 40-year-old woman with neurofibromatosis but no spinal deformity. The meningocele was 4 cm. by 5 cm. by 5 cm. and was situated at T_8-T_9 on the left side. It was diagnosed preoperatively by myelography and successfully excised. The second case was

TABLE I. CASES OF INTRATHORACIC MENINGOCELE FROM THE LITERATURE

AUTHOR	DATE	NUMBER OF CASES	AGE (YEARS)	SEX	WITH VON RECKLINGHAUSEN'S DISEASE	KYPHOSCOLIOSIS	SIZE	SITE	TREATMENT	RESULT
Pohl	1933	1	47	F	Yes	Yes		T_4, Right	Excision	Died; empyema
Schüller and Uiberall	1938	1	56	M	Yes	Yes		T_6, Right	Section nerve root, T_6-T_7	Died; cardiac arrest
Ameuille, Wilmoth, and Kudelski	1940	1	48	F	No	Yes		T_8-T_9, Right	Cyst, packed with gauze	Died; empyema
Cabello-Campos	1946	1	7	M	No	Yes	5 cm. diameter	Upper Thoracic, Right	Nil	Unknown
		1	54	M	Yes	No		T_3, T_4, T_5, Right	Unknown	Unknown
Freedlander	1946	1	Middle Age	F	Yes			?	Unknown	Unknown
Sengpiel, Ruzicka, and Lodmell	1947	1	21	M	No			T_1-T_2, Right	Operation, aspiration of cyst	Recovered
Welch, Ettinger, and Hecth	1948	1	41	F	Yes	Yes	Neck 3 cm. by 4 cm.	T_6-T_7, Left	Excision	Recovered
Mendelsohn and Kay	1949	1	40	F	Yes	No	3 cm. by 4 cm. by 8 cm.	T_6, T_7, T_8, Right	Excision	Recovered; headaches
Byron, Alling, and Samson	1949	1	36	F	Yes	Yes	10 cm. diameter	T_2-T_3, Right	Excision	Recovered
		1	61	M	Yes	Yes	7 cm. diameter	C_7-T , Right	Operation	Died; cardiac arrest
Head	1949	1	48	M	?	?	?	?	Aspiration	Unknown
Cross, Reavis, and Saunders	1949	1	22	M	Yes	Yes	4 cm. by 8 cm.	T_8-T_{10}, Right	Nil	Unknown
Kessel	1951	1	23	F	No	Yes	Small	T_5-T_6, Left	Excision	Recovered
		1	8	F	Yes	Yes	3 cm. by 2.5 cm.	T_7-T_8, ?	Unknown	Unknown

Otani	1951	1	40	F	No	Yes	5 cm. by 3 cm.	T_5, Right	Nil	
Ciaglia	1952	1	31	F	Yes	Yes		C_7, Left	Excision	Recovered 3½ years
Rubin and Stratemeier	1952	1	7 weeks	?	?			T_4, Left	Died before treatment could begin	Died
Turunen	1952	1	33	M	Yes	Yes	4 cm. diameter	T_5-T_6, Left	Excision	Recovered
Cmyral	1952	1	53	M	?	Yes	?	Bilateral	Nil	
Baker and Curtis	1953	1	40	F	Yes	No	4 cm. by 5 cm. by 5 cm.	T_8-T_9, Left	Excision	Recovered
	1953	1	63	M	No	No		T_9-T_{10}, Right	Excision	Died; Paget's disease, 9 months
Sears, Clayton, and Siebel	1953	1	29	F	No	Yes	10 cm. diameter	T_2-T_3, Left	Excision	Recovered
Gernez-Rieux and LePaul	1954	1	59	M	No	Yes	4 cm. diameter	T_{11}-T_{12}, Right	Nil	
Hackensellner	1954	1	45	F	Yes	Yes	5 cm. diameter	T_9-T_{10}, Bilateral	Nil	Died
Wilhelm	1954	1	38	F	Yes	Yes	5 cm.	T_1, Right	Operation	Died
Nanson	1956	1	43	F	Yes	Yes	15 cm. diameter	T_3-T_4, Right	Excision	Recovered

a 63-year-old man with no neurofibromatosis and no spinal deformity. The patient had Paget's disease. At operation, a cyst was found at level T_9-T_{10} on the right and the diagnosis was established by a type of Queckenstedt's test, with a needle in the cyst. It was successfully excised but the patient died nine months later of Paget's disease.

Sears, Clayton and Siebel,[17] in 1953, record a meningocele in a 29-year-old Negro woman with no evidence of neurofibromatosis. Kyphoscoliosis was present. She had a meningocele, 10 cm. in diameter, situated at level T_2-T_3 on the left side. It was successfully removed.

Three further examples of intrathoracic meningocele were reported in 1954. Gernez-Rieux, and LePaul[18] describe the case of a 59-year-old man with a meningocele on the right side at the level of T_{11}-T_{12}. Kyphoscoliosis was present, but no generalized neurofibromatosis. The diagnosis was made by Lipiodol injection. No treatment was given to the patient. In Germany, Hackensellner and Pape[19] report the case of 45-year-old woman who died of a cerebral tumor. She was found to have bilateral meningoceles situated at the level of D_9-D_{10}. The one on the right side was about the size of an apple and that on the left a little smaller. She had a typical generalized neurofibromatosis. The third case to be reported, in 1954, was that of Wilhelm,[20] who describes a 38-year-old woman who was known to have had a density in the upper right lung field for five years. Four years later, it had enlarged and she had pain in the right shoulder and shortness of breath. She suffered from typical von Recklinghausen's disease and had kyphoscoliosis of the upper dorsal and cervical spine. The meningocele was the size of an apple. She was operated on but died of cardiac arrest and autopsy showed she had a pheochromocytoma as well as an intrathoracic meningocele situated at the level of T_1.

This, therefore, brings the list of recorded cases to 27, including the present case. A table (Table I) has been made setting out the characteristics of all these cases and Table II gives the summary of them according to age, sex, association with neurofibromatosis, kyphoscoliosis, and the side of chest involved. The treatment employed and the results are summarized.

It will be noticed that the average age is 40 years. There is a slight preponderance of females over males. At least 60 per cent are associated with neurofibromatosis and kyphoscoliosis. The right side of the chest preponderates over the left. Fifteen patients have been operated on and, of these, 11 recovered.

It would therefore appear that this syndrome has a predilection for middle-aged females and that the right side is more frequently involved than the left.

The diagnosis should be possible before operation by means of myelography and suitable positioning to cause the opaque medium to enter the sac.

It is interesting to note that thoracic meningocele is not generally recorded as a complication of von Recklinghausen's disease. The usual explanation of

a posterior sulcus tumor in this disease is a neurofibroma. Yet in actual fact this association is extremely rare. It would appear that meningocele is a much more common entity.

Furthermore, in considering mediastinal tumors, meningocele is rarely mentioned in the differential diagnosis. Blades,[21] in his review of 109 cases of mediastinal tumors, does not mention it.

TABLE II. SUMMARY OF CASES INTRATHORACIC MENINGOCELE FROM THE LITERATURE

NUMBER OF CASES	AVERAGE AGE	SEX	WITH VON RECKLINGHAUSEN'S DISEASE	SIDE	TREATMENT	RESULTS	
27	40 years	15 Female	16—Yes	15—Right	16—Operation	Died	7
		11 Male	8—No	7—Left	7—No operation	Recovered	11
		1 Unknown	3—Unknown	2—Bilateral	1—Died before treatment	Unknown	9
				3—Unknown	3—Unknown		

The pathology of the 26 recorded cases has not been well defined by the authors. There are very few reports of the exact nature of the wall of the cyst. The present recorded case shows definite evidence that these meningoceles may not arise in the usual manner, but that they may develop from degeneration within a neurofibroma which subsequently communicates with the subarachnoid space. They may commence as a dumbbell type of tumor. The cyst of this case in general had a wall 0.2 cm. in thickness, but at its lower portion it was 2.6 cm. in thickness and in this area it had the structure of a neurofibroma. Furthermore, in one area of the cyst, a myelinated nerve was found.

Kessel[11] suggested that the etiology was to be found in degenerative processes in the bodies of the vertebrae with out-pouching of the meninges. This cannot be substantiated in this case. It is therefore suggested that these meningoceles may indeed commence as true tumors of nerve tissue origin exactly similar to cutaneous lesions and that the subsequent cyst results from degeneration and cavitation with later communication with the cerebrospinal fluid. It is to be hoped that, in future studies of these lesions, very careful attention will be given to the pathologic and histologic picture of the cyst walls.

Surgical excision of the tumor would appear to be the treatment of choice, as the lesion progresses slowly. However, small meningoceles without symptoms could be safely followed conservatively. Modern surgery makes the excision of the cyst relatively safe provided meticulous closure of the neck is carried out.

CONCLUSION

A case of thoracic meningocele is recorded in association with neurofibromatosis and acute kyphoscoliosis.

This would appear to constitute a syndrome which is not generally recorded in connection with von Recklinghausen's disease.

The condition should be capable of diagnosis preoperatively by means of myelography.

The treatment is excision with careful closure of the neck of the sac.

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ANTERIOR APPROACH TO CARCINOMA OF THE SUPERIOR MEDIASTINAL AND CERVICAL SEGMENTS OF THE ESOPHAGUS

WILLIAM R. WADDELL, M.D.,* AND J. GORDON SCANNELL, M.D.**
BOSTON, MASS.

THE surgical management of cancer of the upper third of the esophagus is difficult because of the relative inaccessibility of the tumor through the usual thoracotomy and cervical incisions and because re-establishment of continuity usually requires advancement of stomach or intestine from the abdomen to the neck. With the conventional approach, removal of large tumors lying in the thoracic inlet requires a combined transpleural and cervical approach with change of the patient's position during the operation. To circumvent these difficulties, we propose excision of carcinoma of the cervical and superior mediastinal segments of the esophagus in selected cases through an anterior sternum-splitting approach with the patient supine throughout the procedure. The distal esophagus and stomach are simultaneously freed through a laparotomy incision and continuity is re-established by gastropharyngeal or high gastroesophageal anastomosis, the stomach being advanced through the anterior mediastinum. Ideally, the operation can be carried out extrapleurally. The application of this approach to the problem of high esophageal lesions in the first 6 patients in whom it has been attempted is the substance of this report.

Operative Method.—The entire procedure is carried out with the patient in the dorsal decubitus. The neck, anterior chest wall, and abdomen are prepared and draped. The lateral aspects of the chest are also prepared so that lateral extensions of the sternal-splitting incisions can be made, should they be necessary. Initially, the cervical esophagus is exposed. The skin is incised as for a thyroidectomy and the left end of the incision extended up anterior to the sternocleidomastoid muscle, almost to the mastoid process. Dissection is then carried in front of the muscle, over the carotid sheath and behind the thyroid to expose the upper esophagus and pharynx. Lesions in this region can be inspected and mobilized along with regional lymph nodes. If the lesion is resectable, the skin over the sternum is incised, drapes applied, and the sternum split using a Lebsche knife. Separation of the two halves of the sternum is accomplished with a small rib spreader. This exposes the upper mediastinum. The pleura is pushed back and the left innominate vein interrupted. Further dissection posteriorly along the left side of the trachea exposes the esophagus

From the Surgical Service, Massachusetts General Hospital and the Department of Surgery, Harvard Medical School, Boston, Mass.

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*Clinical Associate in Surgery, Harvard Medical School; Assistant Surgeon, Massachusetts General Hospital, Boston, Mass.

**Clinical Associate in Surgery, Harvard Medical School; Associate Visiting Surgeon, Massachusetts General Hospital, Boston, Mass.

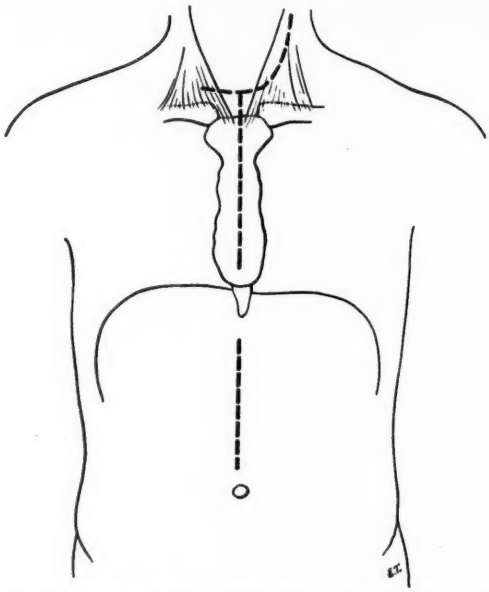

Fig. 1.—The skin incisions used for cervical, mediastinal, and abdominal approach to esophagus and stomach.

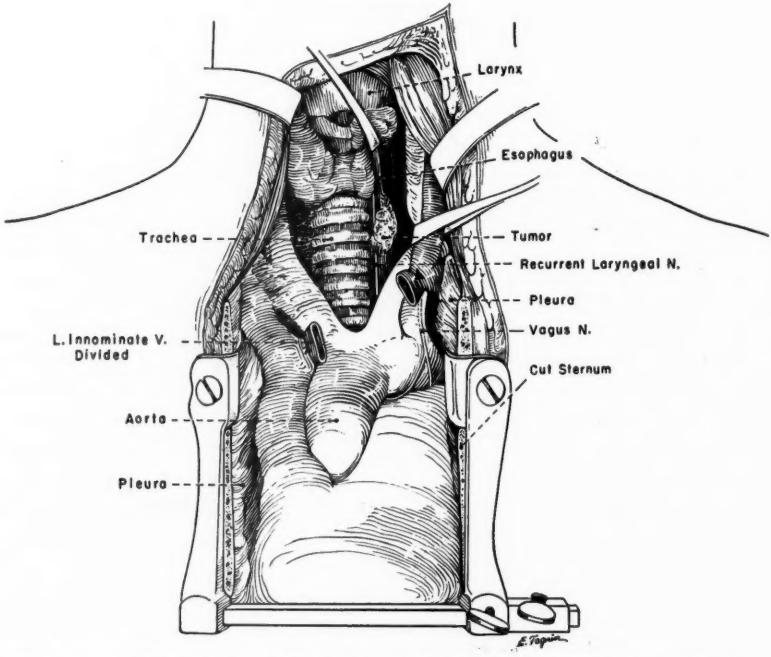

Fig. 2.—The exposure as seen after division of the sternum and left innominate vein.

down to the level of the aortic arch. In dealing with malignant lesions, the left recurrent laryngeal nerve is routinely sacrificed. Mobilization of the supra-aortic portion of the esophagus is easily carried out under direct vision and separation of the esophagus or tumors from the trachea may be safely carried out. If necessary, portions of the membranous trachea can be excised. In one case, here reported, the tracheal rings were flexible and allowed linear suture of such a defect with only moderate narrowing of the trachea. The esophageal arteries arising from the aortic arch and from bronchial arteries can be secured and ligated under direct vision. Access to the upper mid-esophagus can be facilitated by gently lifting the aortic arch forward and to the left.

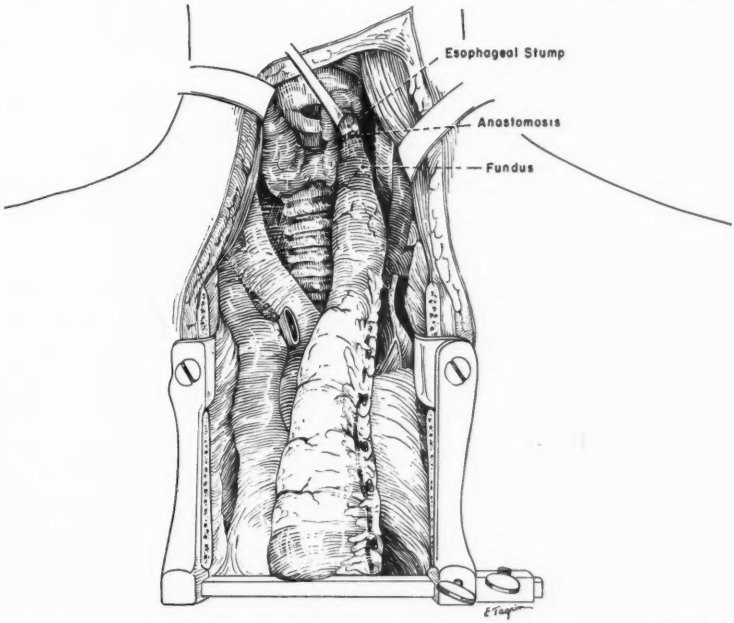

Fig. 3.—The stomach passing through the anterior mediastinum and anastomosed to the uppermost portion of the esophagus after esophagectomy.

In this manner, the normal portion of the esophagus can be freed down to the level of the carina with relative ease. Beyond this, the esophagus is freed by finger dissection. Although occasionally individual vessels can be clamped and ligated, it may be necessary to interrupt several small vessels without ligature. We have seen only minimal bleeding from such a maneuver.

As soon as the resectability of the lesion is established, a second team begins mobilization of the entire stomach through a midline upper abdominal incision. The freeing of the stomach is carried out so as to preserve the right gastric and right gastroepiploic vessels. The short gastric and left gastroepiploic vessels are divided. The left gastric artery is secured near its origin

to preserve continuity between right and left gastric vessels along the lesser curvature. The surgeon working from the abdominal approach mobilizes the lower esophagus and draws it down much as in the performance of a transabdominal vagotomy. Through the hiatus, the lower esophageal vessels can be pulled down with a finger and the proximal portions clamped and ligated. Occasionally, a vessel cannot be reached with instruments. If so, it is simply stripped out of the esophageal wall and allowed to retract. In this manner, the dissection from above meets the dissection from below. The entire esophagus is thus freed and, after severance from the stomach, delivered into the superior mediastinum. The mobilized stomach is brought through an opening in the anterior portion of the diaphragm into the anterior mediastinum. The stomach will reach the pharynx by this route without undue tension. A three-layer anastomosis between the stomach and pharynx, or esophageal stump, is made. For this, fine interrupted silk sutures are used.

The abdominal wound is closed in layers using through-and-through stay sutures. The sternum is wired with heavy steel wire.

It is important to establish a tracheostomy before withdrawal of the endotracheal tube. This can be placed to the right of the midline so that the tracheostomy does not communicate with the area of mediastinal dissection.

CASE REPORTS

CASE 1.—M. G. H. (No. 866878), a 62-year-old man, was transferred to the Massachusetts General Hospital from a state tuberculosis sanatorium because of esophageal obstruction of two weeks' duration. He had been treated for extensive fibrocaseous pulmonary tuberculosis for eight years. For five years, he had been paraplegic as a result of cord compression due to tuberculosis of the spine. Roentgenograms demonstrated a filling defect in the cervical esophagus extending down 7 cm., from a point 3 cm. below the cricopharyngeus muscle. There was also extensive fibrosis of the upper lung fields. Bronchoscopy showed a paralyzed left vocal cord and some anterior displacement of the trachea without invasion.

On April 7, 1955, a total esophagectomy and pharyngogastrostomy was carried out through cervicomediastinal and abdominal incisions. A tracheostomy *was not* established.

Postoperatively, he had copious tracheobronchial secretion but coughed effectively until, on the eighth day after operation, the sternal wound separated. About the same time, orally ingested liquids appeared from the mediastinum. A tracheostomy and a feeding jejunostomy were made. Despite these measures he gradually deteriorated and died on the twenty-eighth postoperative day.

Post-mortem examination revealed a tiny leak at the gastropharyngal suture line, dehiscence of the sternal wound resulting from cutting through the bone by wire sutures, localized infection of anterior mediastinum (anterior to transplanted stomach) in continuity with the open sternal incision, pulmonary congestion and edema, pneumonitis, severe tracheobronchitis, fibrocaseous pulmonary tuberculosis, tuberculosis of the spine, chronic cystitis with calculi, pyelonephritis acute and chronic, and atrophy of the spinal cord distal to compression at the collapsed eleventh dorsal vertebra.

CASE 2.—M. G. H. (No. 891317), a 70-year-old doorman, entered the hospital with progressive dysphagia of four months' duration. At the time of entry he could swallow only thin liquids. There had been a 20-pound weight loss. Physical examination and all laboratory tests were normal. Radiologic examination with barium showed a large obstructing lesion extending down 4.5 cm. from the level of the sternal notch.

On May 13, 1955, a total esophagectomy was carried out through cervicomediastinal and abdominal incisions. Gastrointestinal continuity was re-established by pharyngogastrostomy—the stomach being advanced through the anterior mediastinum. The tumor invaded the membranous portion of the trachea, a 2 cm. segment of which was removed. The tracheal rings were pliable and it was possible to make a linear closure with only moderate narrowing, posteriorly. One lymph node, of eight examined, contained tumor. The postoperative convalescence was uncomplicated. The patient was discharged on the fifteenth postoperative day.

Approximately six weeks after discharge, a course of radiation amounting to 6,000 r (tumor dose) was given over a period of one month. Shortly thereafter he returned to work. He has remained well during the ensuing year.

CASE 3.—M. G. H. (No. 894762), a 58-year-old truck driver, entered the hospital complaining of dysphagia of two months' duration. The esophagus was completely obstructed and he had lost 21 pounds of body weight. Except for weight loss there was no physical abnormality. Roentgenographic examination showed an extensive lesion consistent with carcinoma which extended from the hypopharynx to below the aortic arch. Bronchoscopy showed displacement of the trachea but no actual invasion of tumor through the mucosa.

On June 9, 1955, an exploratory operation was performed through a cervicomediastinal incision. The trachea was invaded extensively and there were many grossly involved lymph nodes. The lesion was not resectable. A tracheostomy was established.

The postoperative convalescence was uncomplicated. The patient subsequently died of pneumonia during radiation treatment, presumably having developed a tracheoesophageal fistula as a result of necrosis of tumor.

CASE 4.—M. G. H. (No. 911324), a 56-year-old housewife, came to the hospital because of a 20-pound weight loss and dysphagia. She could eat soft foods with difficulty. Physical examination and all laboratory examinations were normal. Radiographic examination of the esophagus showed an extensive filling defect extending from the cervical region to below the aortic arch. Bronchoscopy showed no involvement of the trachea.

On Nov. 21, 1955, esophagectomy and cervical esophagogastrostomy were carried out through cervicomediastinal and abdominal incisions. During this procedure, the azygos vein was accidentally divided. It was necessary to open the right pleural cavity to control bleeding. The tumor was rather extensive, measuring 8 cm. in length. There were metastases to two paratracheal lymph nodes and three of fourteen paraesophageal nodes, all adjacent to the tumor. In this patient an attempt was made to avoid a tracheostomy. However, this was necessary four days later because she had difficulty raising secretions. On the sixteenth postoperative day, a cervical abscess with a fistulous communication to the esophagogastric anastomotic line was drained.

The fistula gradually closed over the next month, and a course of radiation (3,000 r tumor dose) was given to the upper mediastinum and cervical area. Slow convalescence has continued to date.

CASE 5.—M. G. H. (No. 916654), a 65-year-old carpenter, came to the hospital complaining of dysphagia of three months' duration. Despite a 30-pound weight loss he was still obese. The heart was enlarged, and was fibrillating at a slow rate. He had been taking digitalis for several years. Roentgenographic examination of the esophagus with barium showed a large filling defect involving the upper third of the esophagus. Other laboratory and special diagnostic studies, including bronchoscopy, were normal.

On Feb. 3, 1956, a total esophagectomy with pharyngogastrostomy was performed. The carcinoma of the esophagus extended for a distance of 6 cm., the upper edge being at the cricopharyngeus muscle. There were two lymph nodes involved by tumor. Two days following operation, an embolus lodged in the left brachial artery. An embolectomy was performed with restoration of normal circulation to the extremity. Convalescence was then uneventful until the tenth postoperative day when the patient suddenly died. Autopsy showed a pulmonary embolus to be the cause of death. The mediastinum and the pharyngogastric anastomosis were well healed.

CASE 6.—M. G. H. (No. 920032), a 60-year-old man, entered the hospital with complete esophageal obstruction. He was emaciated and an indefinite tumor could be palpated in the base of the neck. Roentgenograms showed an extensive ulceration of the esophagus from the pharynx to below the aortic arch. The larynx was invaded and the left vocal cord was paralyzed. A bronchoscope could not be inserted.

On March 22, 1956, the neck and mediastinum were explored. An extensive carcinoma of the esophagus which invaded the larynx and the entire trachea was found. A tracheostomy and a gastrostomy were made. The immediate postoperative convalescence was uneventful. Radiation was begun but the patient deteriorated rapidly and died of bronchopneumonia.

DISCUSSION

There are several advantages of this method of dealing with lesions of the upper esophagus. It allows easy and direct exposure of the esophagus from the aortic arch to the pharynx. This is possible because of the slight deviation of the esophagus to the left and the ease with which the trachea and esophagus can be rotated to allow dissection. With tumors in the thoracic outlet, the entire dissection of the tumor can be carried out with a single exposure. This avoids partial dissection of the lower end of the tumor from within the chest and the upper end of the lesion from the neck. Once the sternum has been split and the left innominate vein divided, the exposure of the mediastinum is adequate. One of the impressive features of this exposure is the shallow depth between the anterior bony thorax and the anterior surface of the vertebral bodies in the neck and upper thorax. Lower in the thorax, the anteroposterior diameter is greater and exposure of the esophagus more difficult due to the posterior inclination of the spine as it curves dorsally. Nevertheless, dissection is straightforward down to the level of the left main-stem bronchus.

The second advantage of this method of performing total esophagectomy is that neither pleural cavity needs to be entered. Since most of the patients are in older age groups, this feature may allow operation in some patients that otherwise would be considered unable to withstand operation. The pleura was entered in only one of the 6 patients on whom this procedure has been carried out.

The third possible advantage of this approach to lesions of the upper esophagus is that gross extensions of tumor to lymph nodes in both the cervical and upper mediastinal areas can readily be removed with the primary tumor. In each of the 4 patients on whom resections were performed, there were tumor-bearing lymph nodes adjacent to the main tumor and in the sulcus between the trachea and esophagus. In 2 patients, the left lobe of the thyroid was adherent to cervical tumors and was removed in continuity.

The disadvantages of this procedure are several. If one utilizes the stomach for restoration of continuity, the entire distal esophagus must be removed. This involves more or less blind dissection of the esophagus from the level of the carina down to the diaphragm. Although significant bleeding from esophageal arteries stripped from the esophagus wall has not been encountered, this is an inherent danger that might require a radical extension of the approach. In one case, the azygos vein was inadvertently divided and it was necessary to extend the incision into the right pleural space to control bleeding.

On the basis of our limited experience with this procedure, it appears that a logical modification might be to transect the esophagus beneath the tumor, turn in the distal cut end, resect the tumor and adjacent lymph node areas and restore continuity by transplantation of the colon or jejunum through the anterior mediastinum. In most patients, mobilization of the colon is more readily accomplished than freeing of the stomach. Particularly in obese and thick-chested individuals, the transabdominal exposure that permits dissection to mobilize the stomach is difficult to obtain. Complete longitudinal division of the sternum aids in exposure since the costal margins can be separated once the sternum is split, but even with this aid to exposure this portion of the operation may be difficult and time consuming.

The postoperative care of these patients requires that certain precautions be taken. A tracheostomy must be performed. The transplanted stomach continues to secrete and after the patient begins to take liquids there may be gastric retention. The stomach becomes subject to the same fluctuations in pressure as other intrathoracic viscera and especially during coughing there may be regurgitation into the pharynx and spill over into the trachea. Also the dissection about the pharynx causes temporary disturbance of swallowing mechanisms. There may be aspiration of variable amounts of fluid and food for days, or even weeks, after operation. A tracheostomy is necessary to deal with this complication. After transplantation of the stomach into the thorax, a Levin tube should be left in place and aspirated continuously, until the patient can be upright while taking fluids and until satisfactory emptying of the stomach has been demonstrated.

SUMMARY

A technique for performing total esophagectomy through cervical, transsternal, and abdominal incisions is described. This method has been used for the removal of cervical and superior mediastinal carcinoma of the esophagus. Gastrointestinal continuity has been re-established by gastropharyngostomy or high gastroesophagostomy, the stomach being advanced through the anterior mediastinum.

We are indebted to Dr. Edward D. Churchill for pointing out the merits of a cervicothoracic approach to a variety of lesions that arise in the superior mediastinum and upper thorax.

SURGICAL TREATMENT OF DISSECTING ANEURYSM

RICHARD A. GILMAN, M.D.,* AND CHARLES P. BAILEY, M.D.**
PHILADELPHIA, PA.

DISSECTING aneurysm has been recognized as a clinical diagnostic and pathologic entity for many years. The disease itself has been described extensively in the literature. Classic among these are the pathologic works of Erdheim[3, 4] and Moritz,[7] the very minute clinical and pathologic study of Shennan,[9] and the clinical review of Levinson, Edmeades, and Griffith.[6]

In spite of all the clinical and pathologic work which has been done, a review of the world literature reveals that proposals for treatment of this condition have been sporadic and scant.

The natural history of the course of dissecting aneurysm suggests a rational approach to the surgical therapy. Once dissection has been initiated there are two avenues of termination. The first is ultimate rupture through the adventitia with hemorrhage and death. The second is a final rupture back through the intima into the aortic lumen with the formation of a "double-barreled" aorta. This represents the so-called "healed aneurysm" which is compatible with life for an indefinite period, but which occurs only in approximately 10 per cent of cases.[10]

Gurin, Bulmer, and Derby,[5] in 1935, were the first to attack a dissecting aneurysm surgically. While operating upon a patient to relieve obstruction to the iliac artery caused by a dissecting aneurysm, they opened the intima allowing the blood in the channel of dissection to return to its normal passage. The patient died on the sixth postoperative day. The case, however, initiated the concept of the surgically created "healed aneurysm." It was not until 1955 that Shaw[8] reported the second attempt. He not only fenestrated the aorta, this time in the abdominal portion, but sutured the dissected layers together distally. This was a second important step as it prevented further dissection beyond the re-entrance point. This patient died on the ninth postoperative day. DeBakey, Cooley, and Creech,[1, 2] in 1955, reported 6 cases treated by surgery with four survivals. Their techniques varied, but basically consisted of transection of the descending aorta with suture of the cut end of the distal segment of the split media and intima of the inner tube to the media and adventitia of the outer, thus obliterating the entrance of blood into the external passage distally. When it was feasible to resect the dissected proximal portion of the aorta entirely, it was

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*Resident Physician, Department of Thoracic Surgery, Hahnemann Medical College and Hospital of Philadelphia, Pa., National Heart Institute Trainee.

**Professor and Head of Department of Thoracic Surgery, Hahnemann Medical College and Hospital of Philadelphia, Pa.

replaced with a homograft. If the dissection had involved the arch or ascending aorta, "A window was cut in the intima above and the remainder of the wall was then sutured to obliterate the false passage. Distally, the dissected layers were approximated by a continuous circular suture and the ends of the aorta anastomosed."[2]

These operative procedures attempt to produce a "healed aneurysm," and offer an opportunity for the cure of this otherwise almost hopeless disease. It is worth while to point out that the extent of the dissection and the origin of the initial split in the intima will necessitate modifications of the application of the surgical concept of creation of a "healed aneurysm."

Shennan,[9] who catalogued the largest series of dissecting aneurysms, listed in great detail the extent of the dissection in 297 cases. In 121 instances, the dissection remained limited to the ascending aorta or arch. In 104 cases, it started in the ascending aorta or arch and extended for a variable distance into the descending aorta and sometimes beyond the iliac arteries. In only 62 individuals, did it start at the origin of the left subclavian artery or within the descending aorta so that the arch was entirely free of the dissection. In 10 cases, the dissection started in the abdominal aorta (below the level of the diaphragm).

This is a very clear demonstration of the necessity for modifications that will enable one successfully to attack all such possible problems.

Arterial homografts or substitutions will be most useful in caring for those cases where the dissection has begun beyond the arch or in the abdominal aorta. The full concept of the "healed aneurysm" will be applicable where the dissection has started in the ascending aorta or arch and progressed into the descending aorta or beyond. This still leaves the very large group of patients in whom dissection is only within the arch or ascending aorta and for which no operative procedure has been suggested. Transection of the ascending aorta or arch with present-day methods would seem to be impractical.

The following is the report of an operative case with survival in which a "double-barreled" aorta was created. During the operative procedure, a possible method of treating those patients in whom the dissection is limited to the ascending aorta or arch was suggested.

CASE REPORT

The patient, (F. W.) hospital No. 55-10107, a 64-year-old white man, was in good health until Sept. 2, 1955. While presiding at a meeting, he developed severe interscapular pain which did not radiate and accompanied by profuse sweating over his entire body. There was no precordial pain. He was hospitalized in his community hospital. One-half grain of morphine did not control the pain, but an additional 150 mg. of Demerol alleviated it. His past medical history revealed that he had been treated for moderate hypertension of 150-160/100 mm. Hg for ten years. At the time of the discovery of his hypertension, a positive serology was noted which was treated with bismuth and arsenicals. The serology remained positive.

Physical examination showed an obese white man in acute distress who presented a shocklike picture with cold clammy sweat over his entire body and a marked pallor. Blood pressure was 160/100 mm. Hg. Examination of the heart revealed a normal sinus rhythm with occasional ventricular extrasystoles; no murmurs were heard. The chest was clear. Reflexes were equal and within normal limits in both lower extremities.

The pain was ameliorated with Demerol; severe paroxysms of cough were controlled with Dilaudid. These coughing episodes were accompanied by cyanosis which necessitated continuous oxygen therapy. On Sept. 3, 1955, he developed moist râles throughout both lung fields. X-ray of the chest was interpreted as showing a diffuse dilatation of the ascending aorta, arch, and descending aorta (Fig. 1). A diagnosis of a syphilitic aneurysm of the aorta was made and the patient was transferred to the Thoracic Surgical Service of the Hahnemann Hospital, in Philadelphia, on Sept. 4, 1955. Here a clinical diagnosis of dissecting aneurysm of the thoracic aorta was made.

Upon admission, he was still complaining of pain in the interscapular area and, in addition, a diffuse type of abdominal pain. Blood pressure was 170/80 mm. Hg. There were expiratory wheezes and moist râles throughout both lung fields. The heart revealed a normal sinus rhythm with no murmurs. The abdomen was negative with no tenderness or spasm on palpation. Reflexes were equal and active, and good arterial pulsations were present in the lower extremities.

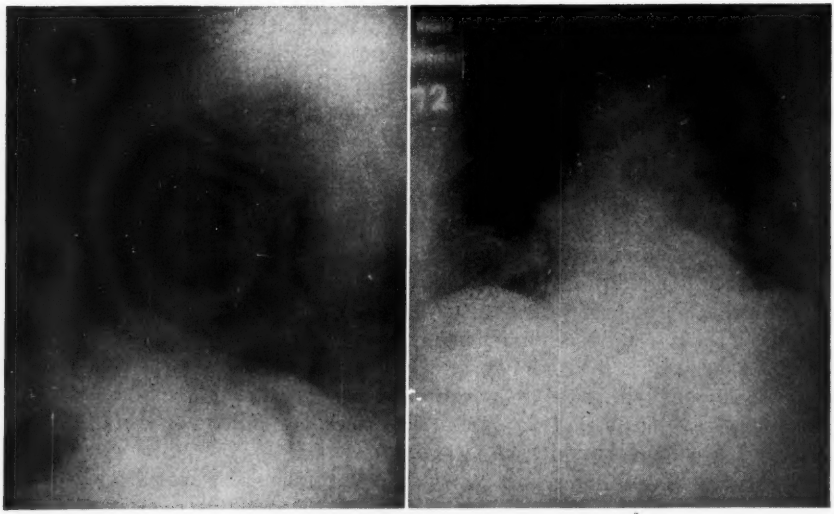


Fig. 1.—Posterior anterior and left lateral view of the chest demonstrating what appears to be a diffuse dilatation of the thoracic aorta.

Laboratory data: Hemoglobin, 14.8 mg. per cent; hematocrit, 50; sedimentation rate, 16 mm./hr.; white blood count, 17,650; segmented cells, 83 per cent; basophils, 1 per cent; lymphocytes, 9 per cent; and monocytes, 7 per cent. Urinalysis was normal. An electrocardiogram demonstrated a normal sinus rhythm with occasional ventricular extrasystoles. The S-T segments were depressed in all leads, and the T waves were of small amplitude or biphasic in all leads. These studies were interpreted as showing left ventricular strain and myocardial damage. Routine x-ray studies showed a generalized dilatation of the distal aortic arch and the descending aorta.

On Sept. 7, 1955, an aortogram was done, using 70 per cent Diodrast administered through a catheter inserted into the left brachial artery. It showed that there was less than the expected amount of luminal dilatation of the aorta but that a double contrast shadow began at the point of origin of the innominate artery and extended parallel with the left half of the aortic arch and the descending aorta (Fig. 2). This double shadow was on the superior margin of the arch. This demonstration was considered confirmatory of the clinical diagnosis of dissecting aneurysm.

The patient was prepared and taken to surgery on Sept. 9, 1955.

Operative report: A standard left posterolateral thoracotomy incision was made, widely opening both the fourth and seventh intercostal spaces to gain complete access to the entire thoracic aorta. Inspection revealed that the proximal portion of the aortic arch was only slightly dilated while the distal arch and descending aorta were dilated to approximately three times their normal size. The adventitia had an ecchymotic appearance. It had been planned to anastomose a whole homologous aortic arch graft obliquely end-to-side to the proximal arch, to divide the lower thoracic aorta, to repair the split coats of the distal segment and to establish continuity by an end-to-end anastomosis between the graft and the lower segment. Later, the upper dissected segment would have been excised. After application of the modified Satinsky clamp to the ascending aorta, the excluded portion was opened. Two lumens were found in what had appeared to be a normal aorta. Feeling that our previous plan was illogical, the opening was closed and the thought of substitution of a graft for the diseased segment of aorta was abandoned. The opening in the ascending aorta was repaired.

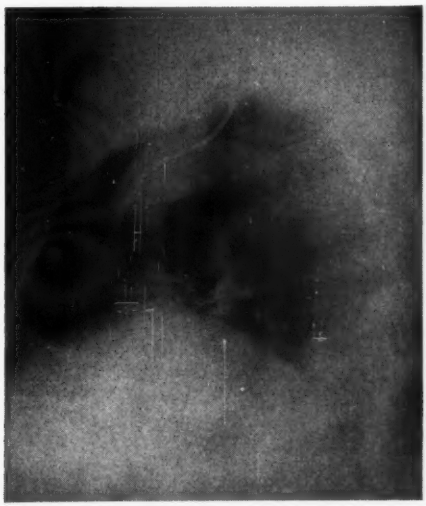


Fig. 2.—Aorta outlined with 70 per cent Diodrast. A double contrast shadow is seen beginning at the origin of the innominate artery and extending parallel with the left half of the aortic arch and the descending aorta.

A modification of the method of DeBakey, Cooley, and Creech was chosen instead. The descending aorta was dissected free, two pairs of intercostal arteries being divided. The aorta was doubly cross-clamped at widely separated points. The combined adventitia and outer portion of the split media were incised transversely into the false lumen anteriorly and on both sides, leaving the posterior half of its continuity intact. This prevented separation of the two ends, facilitating and expediting the final anastomosis. The dissection was found to encompass the entire wall, creating a true double-barreled tube. A great deal of soft, jellylike, black clot was evacuated from the false lumen (Fig. 3). The inner tube, consisting of split media and intima, was divided in its entire circumference (Fig. 4). The cut end of the distal split wall, was repaired using a continuous arterial suture of No. 4-0 silk, obliterating the false lumen at this level (Fig. 5). The proximal cut end of the external tube, consisting of the adventitia and the outer portion of the split media, was sutured to the entire thickness of the reconstituted wall of the distal segment by an over-and-over suture of No. 4-0 arterial silk (Fig. 6). This was accomplished with ease, and gave a

strong suture line. The final result was the creation of two separate tubes proximately emptying into one combined distal tube. The area of the suture line then was reinforced with a circumferentially placed cuff of nylon fabric (Fig. 7). The time of circulatory occlusion was exactly 30 minutes. During the operative procedure, the patient was given Arfonad to maintain his arterial pressure at a level of about 70 mm. Hg, systolic.

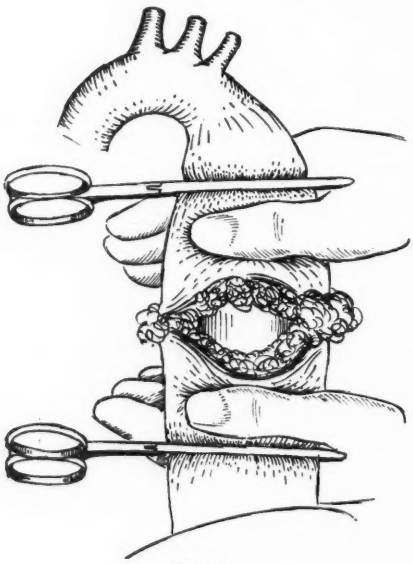


Fig. 3.

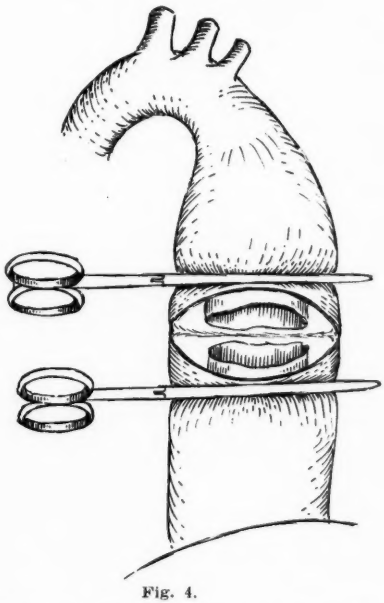


Fig. 4.

Fig. 3.—The outer coats of the dissected wall have been divided transversely leaving the posterior wall of the outer coats intact. The inner tube remains intact at this stage. By gently loosening the clamps and milking the aorta, the clot in the outer channel is removed.

Fig. 4.—The inner tube has been divided transversely throughout its entire circumference.

Postoperative course: The patient responded well from the anesthesia. During the first 24 hours, a persistent hypotension was managed with l-norepinephrine and whole blood. In the first 24 hours, there was an output of 240 c.c. of urine, which in the next 48 hours increased to 40 c.c./hr. After the first 24 hours, the patient's circulation became stabilized, and his course was satisfactory. The patient was placed on anticoagulants 12 hours after surgery and these were continued until the twelfth day. Check x-rays the day after surgery showed a small collection of fluid in the left pleural space which was proved to be dark unclotted blood (by thoracentesis). On Sept. 21, 1955, x-ray again revealed evidence of fluid in the pleural cavity. This time 200 c.c. of clear straw-colored fluid was removed. No further fluid accumulated. The patient's progress was slow but he continued to show improvement until Oct. 5, 1955. He then started to vomit and developed anorexia. During the next few days, a progressive increasing jaundice appeared. Cephalin flocculation was 4 plus, thymol turbidity 3.7 units, alkaline phosphatase was 4.3 units, total bilirubin was 12.6 mg. per cent, urobilinogen was present in the urine, and the stools were not acholic. The liver was enlarged and tender. A diagnosis of infectious hepatitis was made and the patient treated for it. His jaundice subsided and his appetite improved. No further difficulties were encountered and the patient was discharged in good condition to his home on Oct. 28, 1955. He has continued to improve, and is quite well at the time of submission of this manuscript for publication.

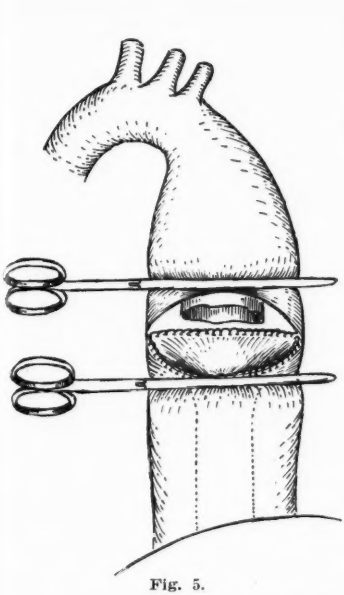


Fig. 5.

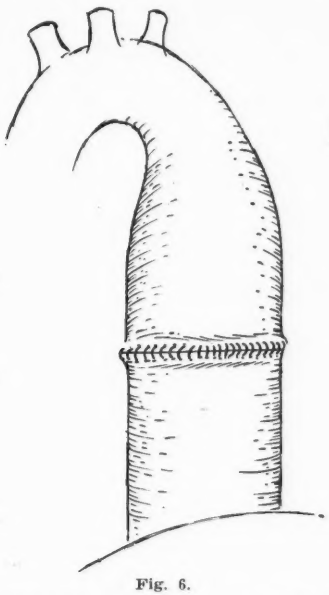


Fig. 6.

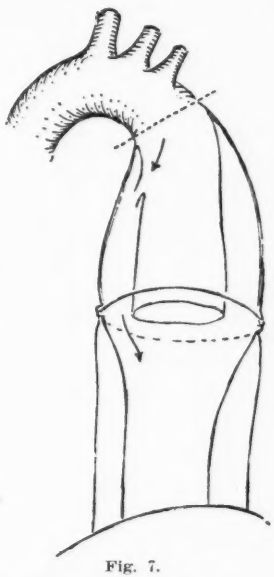


Fig. 7.

Fig. 5.—The distal split coats are sutured together with a continuous over and over suture of No. 4-0 arterial silk. This effectively reconstitutes the distal aorta.

Fig. 6.—Proximal outer coats of the dissected aortic wall are now sutured to the entire distal reconstituted wall with No. 4-0 arterial silk with a simple over-and-over stitch.

Fig. 7.—Diagram showing blood flowing proximally in both the outer dissected channel and in its true path into the reconstituted distal aorta.

DISCUSSION

The method of creating a complete "double-barreled" aorta with establishment of a completely free continuity between the true and false lumina at a level well below the site of initial dissection represents a logical modification and extension of the method devised by DeBakey, Cooley, and Creech. By diverting the entire aortic stream into the lumen of the reconstituted lower segment, it would seem that any tendency of a created intimal window to become narrowed, due to clotting or healing, should be eliminated.

The initial attempt to substitute a homologous graft for the dissected aorta in this case led to the suggestion of a possible method of attack upon those relatively numerous dissections which remains limited to the ascending aorta or arch.

By the application of a modified Satinsky clamp of the type used to isolate a portion of the aorta for the attachment of a pericardial pouch for transaortic commissurotomy (Fig. 8), a portion of the outer dissected layer might be excluded and then incised (Fig. 9). Then, a pericardial pouch could be affixed to the lips of the incision. Through this, an exploring finger could be inserted to determine the extent of the dissection accurately (Fig. 10). With a hooked knife, such as was used originally in the performance of mitral commissurotomy,

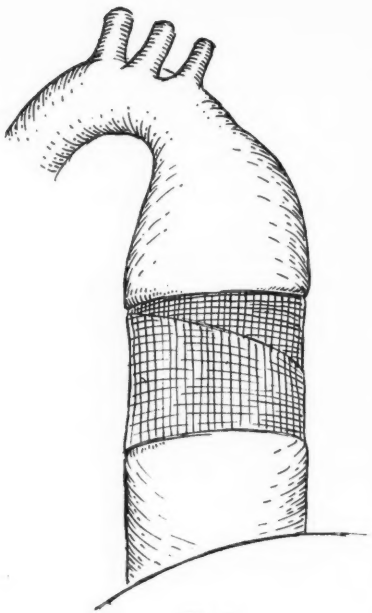


Fig. 8.

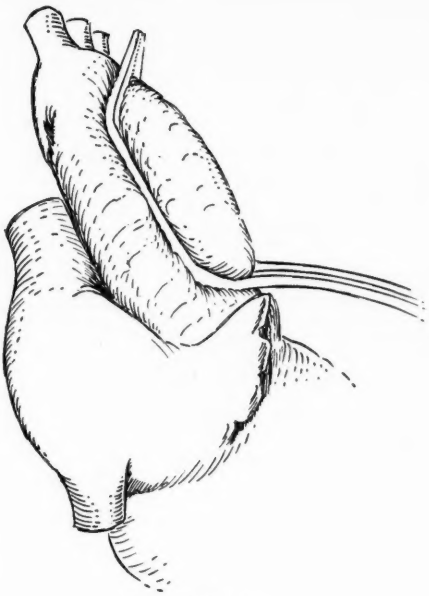


Fig. 9.

Fig. 8.—The entire area of the suture line is wrapped with nylon for reinforcement.

Fig. 9.—A portion of the dissected ascending aortic wall excluded by a modified Satinsky clamp.

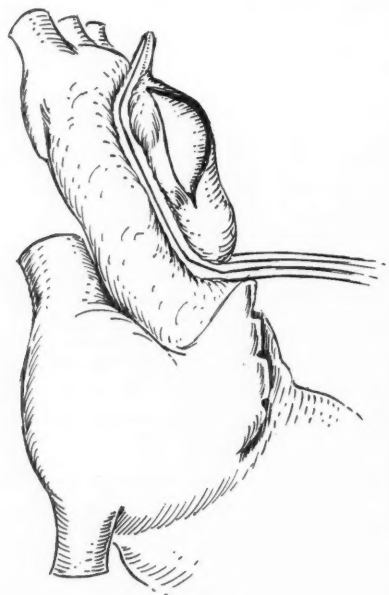


Fig. 10.

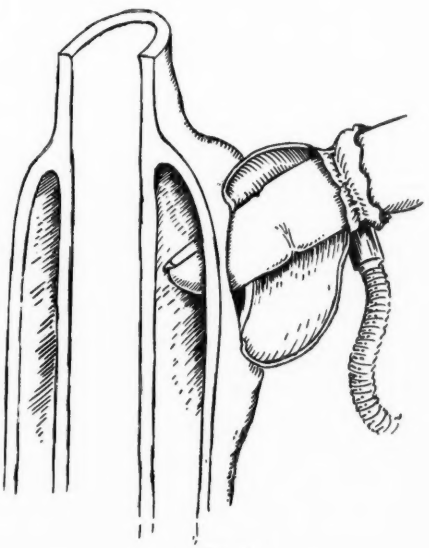
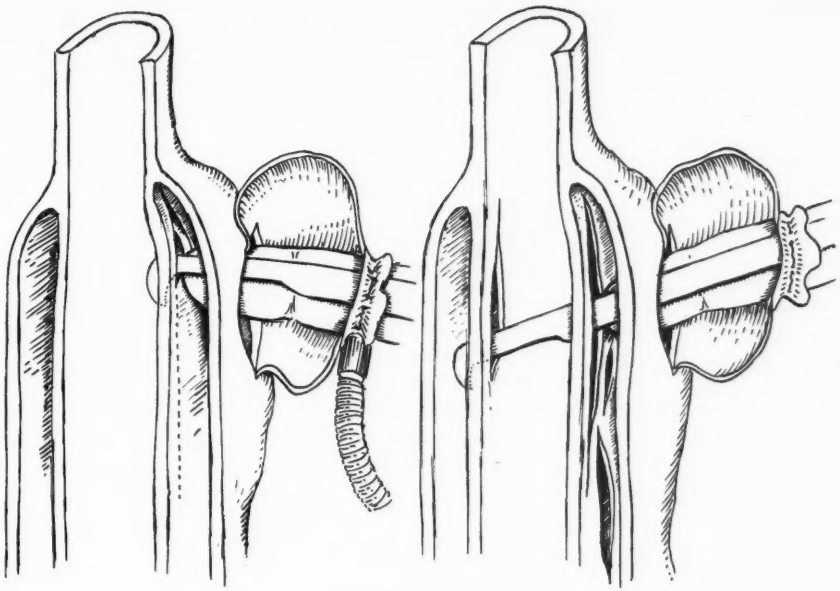


Fig. 11.

Fig. 10.—The outer coats have been incised but the inner tube remains intact.

Fig. 11.—A pericardial pouch has been attached to the outer dissected wall (after the manner of attaching a pericardial pouch for aortic commissurotomy) and a finger is inserted to explore the extent of the dissection.



A *B*

Fig. 12.—*A*, A hooked knife (original knife used for mitral commissurotomy) is inserted alongside the finger incising the inner tube from the extent of the dissection proximally. *B*, Since it is felt that one incision is inadequate to provide free re-entrance of the blood into the true channel, multiple splits are made into the true channel.

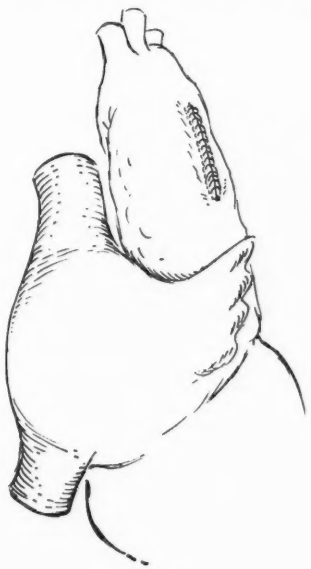


Fig. 13.

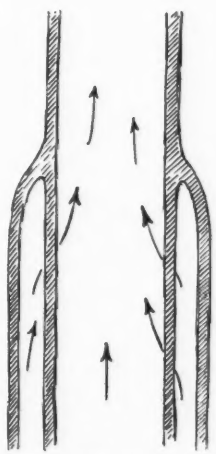


Fig. 14.

Fig. 13.—The clamp has been reapplied, the pericardial pouch removed and the incision in the outer coats repaired.

Fig. 14.—Diagram showing blood coursing in both the true and false channels proximally into the undissected distal channel.

inserted alongside the finger into the pouch, the inner layer then might be repeatedly incised longitudinally to the most distal limit of the dissection (Figs. 11, 12 *A* and *B*, and 13). By reapplication of the clamp, the pouch would be removed and the outer layer of the wall repaired with sutures. This area then might be reinforced with a layer of nylon fabric. Thus, conversion to a "healed aneurysm" would be brought about (Fig. 14).

This would not reconstitute the aorta distal to the new opening, but would tend to alleviate the effective head of dissecting pressure by allowing a run-off into the natural aortic lumen. It is brought to mind that these dissections in this area apparently reach a zone in the media which is resistant to the dissecting force so that frequently they do not progress further but rupture either outward or inward before progression can be resumed. Unfortunately, most often they rupture to the exterior. By the creation of a large vent through which the blood may return to its normal channel, at least the effective head of the dissecting column will be reduced. This will not be complete assurance against further progression, but would seem to be at least a step forward in the treatment of this very large group of dissections which do not progress far enough for more completely definitive surgery before external rupture occurs.

SUMMARY AND CONCLUSIONS

1. The surgical concept of creating a "healed aneurysm" of the aorta has been discussed.

2. A case with survival after the fullest exhibition of such surgical treatment has been presented.

3. A modification of the present method of treatment was used which consisted of leading the two entirely separate lumens into a reconstituted distal segment, thus accomplishing entire diversion of the dissection pressure head.

4. A possible method of corrective approach to dissections which occur only within the arch and ascending aorta is presented.

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FAILURE OF CARDIO-PERICARDIOPEXY TO PROTECT PIGS AGAINST ACUTE CORONARY OCCLUSION

HARRY GROSS, M.D., ALLAN E. BLOOMBERG, M.D., MORTON ROSENBLATT, M.D., ADRIAN KANTROWITZ, M.D., CLARENCE J. SCHEIN, M.D., AND RUTHVEN FERREIRA
NEW YORK, N. Y.

THE purpose of this study was to determine whether the operation of talc cardio-pericardiopexy would protect the pig against acute coronary occlusion. This animal was chosen for two reasons. First, Blumgart and his coworkers showed that the pig heart, like the human, normally has no intramyocardial anastomoses.[1] Second, the rapid growth of the pig in a relatively short period of time makes it possible to evaluate the protective role of talc during a period of rapid growth. Chardack's[2] recent work in the dog further emphasizes the fallacy of using dogs in the study of experimental coronary disease.

METHOD

Yorkshire piglets weighing from 30 to 60 pounds were anesthetized with either intravenous or intraperitoneal veterinary Nembutal. An endotracheal airway was established in all animals. Our earlier attempts were directed at transglottic intubation using specially devised long laryngoscopic blades and tubes. This procedure was not uniformly successful. The later experiments were carried out via transtracheal intubation. In all animals requiring intubation, positive pressure oxygen was administered.

Control Group.—Following intubation, the heart was exposed transpleurally in a group of 6 piglets. The left anterior descending coronary artery was tied 2 cm. or more from its origin. Many of these animals survived. For this reason, the left anterior descending coronary must be ligated within 2 cm. of its origin in order uniformly to kill the animal.

Experimental Group.—Animals were prepared by inserting 4 to 6 Gm. of sterile USP talc (magnesium silicate) into the pericardium. This was done as an extrapleural procedure. All animals received antibiotics postoperatively.

Fifty pigs were used in this phase of the experiment. Twenty-one survived the procedure and were challenged at various intervals from one to fifty-five weeks. The remaining animals were included in the control group used to determine the site of lethal ligation, or were lost due to technical difficulties. The challenge entailed left anterior coronary artery ligation at the site which

From the Medical and Surgical Divisions of the Montefiore Hospital, New York City, N. Y.
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had proved fatal in the control group. These operations were done transpleurally. During the survival period which ranged from one to fifty-five weeks, the older animals increased their weight tenfold so that the largest survivors weighed 600 to 700 pounds.

The anterior left coronary artery was ligated and divided within 2 cm. of its origin. In a few animals, intermittent occlusion by a clamp preceded the final ligation and division of the artery. Continuous electrocardiogram tracings were obtained on all the animals.

EXPERIMENTAL RESULTS

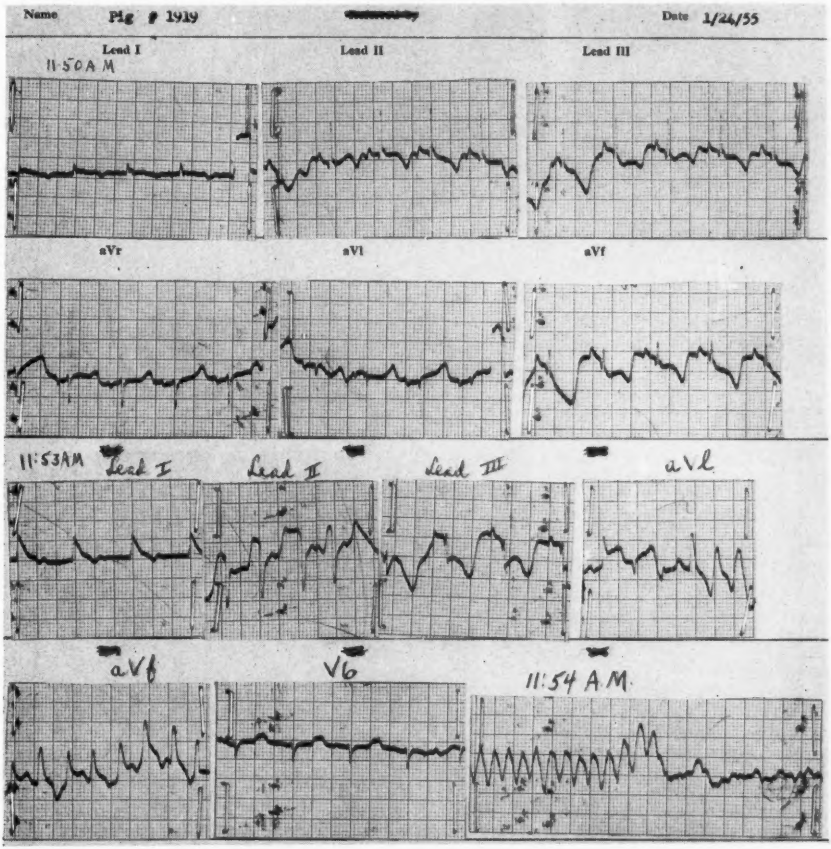
The results are detailed below. It is important to note that in the interval between talc preparation and challenge, there was no interference with the growth or activity of the animal. In no instance was constrictive pericarditis observed.

The electrocardiographic changes resulting from talc were characterized by transitory evidence of pericarditis and myocarditis in the form of lowering of the T waves. The electrocardiographic changes described were all evaluated in relation to the preoperative record. Electrocardiograms taken immediately following ligation of the coronary arteries showed the typical responses to coronary ligation with the development of currents of injury, displacement of the RT or QT segments up or down, the development of T-wave changes, and various types of arrhythmias. Monophasic curves of injury were frequent. Premature beats of the auricle or ventricle, often multifocal, developed; runs of premature ventricular beats that were often the precursors of fatal ventricular tachycardia. In many instances, the transition from normal sinus rhythm to fatal ventricular tachycardia was direct and sudden. In the cases where the occlusion was temporary and released before the onset of ventricular fibrillation, it was possible to restore normal sinus rhythm and to abolish currents of injury.

The period of survival following ligation in the talc-prepared animals paralleled exactly that of the control animals. No animal survived the procedure. The maximum period of survival was 29 minutes.

Pathologic Findings.—The ligation of the left anterior descending coronary artery within 2 cm. of its origin was confirmed in all cases. Since the time between occlusion of the coronary vessel and the death of the animals was short, none of the hearts exhibited gross changes in the myocardium. All showed a grayish-white thickening of the pericardium. In the hearts of pigs surviving one to four weeks after talc installation, there was a fibrinous exudate on the surface of the thickened pericardium. The hearts of longer survivals showed more thickening. The pericardial reaction was greater over the anterior than over the posterior part of the ventricles. Over the posterior surfaces of some specimens, fairly normal pericardium was found. The pericardial reaction was greater near the atrioventricular groove than at the apex. Both of these differences are related to the anterior injection of the talc.

Microscopic Findings.—Sections were taken from the mid- and posterior portions of the interventricular septum and the left anterior ventricular wall. Histologic examination of the specimens showed two types of reaction. In the early cases there was acute pericarditis with an inflammatory reaction. In the later cases, there were scarring and foreign-body granuloma formation with numerous giant cells. In none was there a significant or widespread collateral circulation into the pericardium or myocardium (Figs. 1-4).



Pig # 1919

Ligation of left main coronary artery is followed by rapid changes terminating in ventricular fibrillation four minutes later.

Lead I shows inversion of T waves.
Lead II shows sharply pointed deeply inverted T waves.
Lead III shows RT depression and sharply pointed deeply inverted T waves.
Lead aVf shows profound RT depression.
Three minutes after ligation:
Lead I shows a broadening of the R wave.
Lead II shows a marked shift in axis and marked widening of QRS.
Lead III shows marked RT depression and inverted T waves.
Lead aVf shows multifocal premature beats followed by a run of ventricular premature beats.
Four minutes after ligation fatal ventricular fibrillation developed.

Fig. 1.—Section through pericardium and myocardium (left anterior ventricular wall) of a one-week specimen. Note thickening in pericardium and lack of new small blood vessel formation in either the pericardium or myocardium.

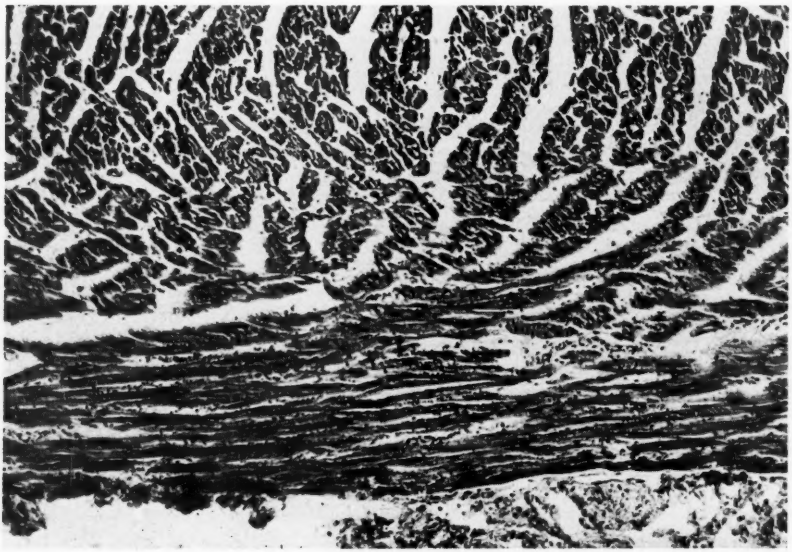


Fig. 2.—Similar section in another one-week specimen. Again note lack of blood vessels in myocardium directly beneath pericardium involved in the talc reaction.

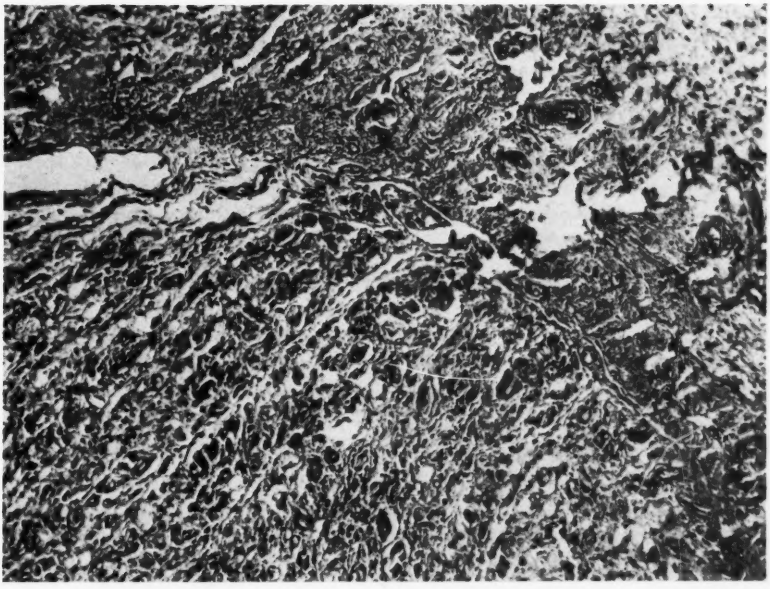


Fig. 3.—A section through the pericardium over the left anterior ventricular wall in a pig that survived five months before the coronary artery was ligated. Note the dense fibrosis surrounding the talc granules, an occasional foreign-body cell, and a very few small blood vessels.

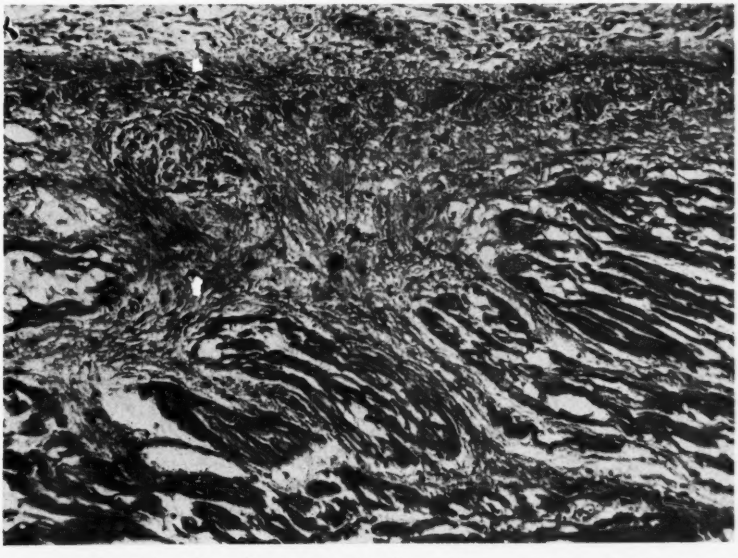


Fig. 4.—This section shows both the pericardium and myocardium from the left anterior ventricular wall in another pig that survived five months. Again note the dense fibrosis in the pericardium with the lack of new blood vessel formation in either the pericardium or myocardium.

DISCUSSION

No beneficial effects resulted from talc cardio-pericardiopexy in protecting the pig heart against subsequent ligation of the coronary arteries.

Pericardial adhesions developed wherever talc powder was insufflated. The adhesions were dense and so avascular that when they were cut, no bleeding resulted. They were firm enough so that they had to be cut by sharp dissection for, when cut by blunt dissection, atrial tears frequently resulted.

During the period of observation, there was no histologic or gross evidence of increased collateral circulation. The experimental animals did not survive any longer than the controls regardless of the duration of talc instillation.

The burden imposed on the coronary circulation by our experiments was great. The ligations were sudden, complete and high, 2 cm. or less distal to the bifurcation of the left coronary artery. Since there was no stimulus for the development of a coronary collateral circulation in our animals by progressive coronary narrowing as in Blumgart's experiments, the burden on the coronary circulation and the test of the effectiveness of pericardio-pericardiopexy were great.

The experimental conditions do not completely mimic the course of human coronary artery disease. In man, the greatest stimulus to a collateral circulation is progressive coronary narrowing. Indeed, when the collaterals are well developed, occlusions of one or both major coronary arteries may be well tolerated. Contrariwise, sudden hemorrhage into a plaque of a coronary artery close to the bifurcation, when coronary disease is local, is usually fatal in man. This clinical condition is simulated in the experiments performed.

SUMMARY

1. In the normal pig, the introduction of talc into the pericardium is well tolerated.

2. Animals surviving talc pericardio-cardiopexy for as long as one year were not protected by this operation against acute occlusion of the left coronary artery.

3. Constrictive pericarditis was not produced in any of the animals.

We are indebted to the Lederle Laboratories Division of the American Cyanamid Company without whose generous help this work could not have been carried out, and to Drs. Kanegis, Percival, and Tonelli of their Staff for much help.

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AN EVALUATION OF TWO NEW TOPICAL ANESTHETIC AGENTS: DYCLONE* AND CYCLAINE**

F. A. Hughes, M.D., J. D. Mobley, M.D., R. J. Bills, M.D.,
J. R. Burwell, M.D., and J. W. Pate, M.D.
Memphis, Tenn.

THE "ideal" topical anesthetic agent should possess the following properties: (1) rapid onset of anesthesia (2) high potency, (3) freedom from untoward reactions in amounts normally employed, (4) wide margin of safety even when absorbed, (5) no local irriation, and (6) no cross sensitization to other anesthetic agents. This paper presents a comparison of two new agents developed in the continuing search for the ideal topical anesthetic agent.

The present study is divided into two parts. The first is a review of the literature on the toxicity of Dyclone and Cyclaine and our toxicity studies on Dyclone, Cyclaine, tetracaine, and cocaine. The second part consists of a clinical evaluation of Dyclone and Cyclaine anesthesia for bronchoscopy, bronchography, esophagoscopy, and esophageal dilatation.

REVIEW OF THE LITERATURE

Beyer, Latven, Freyburger, and Parker[1] compared the toxicity of Cyclaine, cocaine, and other anesthetic agents by the LD_{50} technique. The findings of their study of the toxicity of Cyclaine and cocaine in milligrams per kilogram of body weight are shown in Table I. It is apparent that these two agents are of equal toxicity when given intravenously in mice but, when

Table I

	MICE		RABBITS	GUINEA PIGS	
AGENT	IV (MG./KG.)	SUBCUTANEOUS (MG./KG.)	SUBCUTANEOUS (MG./KG.)	AQUEOUS SOLUTION (MG./KG.)	ADRENALIN SOLUTION (MG./KG.)
Cyclaine	24	1080	164	146	385
Cocaine	25	140	70	27	87

administered subcutaneously, Cyclaine is considerably less toxic, milligram for milligram, in mice, rabbits, and guinea pigs. No report of Cyclaine toxicity studies in dogs could be found. Beyer and co-workers[1] found that as a topical anesthetic agent, Cyclaine is as potent as cocaine when equal concentrations are employed. They also state that 1 and 2 per cent concentrations of Cyclaine give approximately the same duration of anesthesia as the corresponding concentrations of cocaine.

From the Thoracic Surgery Section, Veterans Administration Medical Teaching Group Hospital, Memphis 15, Tenn.
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*Dyclonine hydrochloride—Pitman-Moore Company, Indianapolis 6, Ind.

**Hexylcaine hydrochloride—Sharp & Dohme, Division of Merck & Co., Inc., Philadelphia 1, Pa.

Hudson and Jacques[2] report the use of Cyclaine topically for a variety of procedures, including bronchoscopy, with a negligible incidence of untoward reactions. Clark, Orkin, and Rovenstine[3] state that a 2.5 per cent solution of Cyclaine will anesthetize the larynx in almost every patient for a period of 15 minutes and a 5 per cent solution is effective in all instances for approximately 30 minutes.

Abreu and his associates[4] report that 2 mg./Kg. body weight of Dyclone administered intravenously in anesthetized dogs did not significantly affect blood pressure or pulse, nor did it reduce the cardiovascular response to acetylcholine or increase response to epinephrine, demonstrating a lack of parasympatholytic action. Doses of 5 to 10 mg./Kg. in anesthetized dogs given in a period of one to 2 minutes caused respiratory failure in some animals. In 15 unanesthetized dogs, they found that the dogs tolerated 2.5 to 3.0 mg./Kg. intravenously and 20.0 to 25.0 mg./Kg., orally. The intravenous LD_{50} for dogs was found to be 9.5 ± 1.3 mg./Kg.

Arora and Sharma[5] found 10 mg./Kg. Dyclone fatal to anesthetized dogs when administered in a period of 25 seconds. These investigators describe the pharmacology of Dyclone in detail. Arora, Kulshrestha, and Sharma[6] found Dyclone in a 0.5 per cent concentration to be more rapid in onset and of about equal potency as 5 per cent cocaine or 1 per cent tetracaine when used topically for ophthalmic surgery.

Himalstein,[7] in a recent review of the problem of topical anesthesia prior to peroral endoscopy, concluded that severe and fatal reactions are far more common than generally appreciated. His opinion was that most fatalities are due to overdosage and only a small number due to true drug idiosyncrasy. He points out the wide range of dosage of cocaine and tetracaine employed by different endoscopists. He stressed the importance of using as small a quantity of anesthetic as possible commensurate with adequate anesthesia.

In his experience, lidocaine and Cyclaine showed some promise of supplanting cocaine.

METHOD OF STUDY AND RESULTS

We undertook to determine the intravenous lethal dose of both Cyclaine and Dyclone in dogs and to compare the lethal dose of these agents with those of cocaine and tetracaine similarly administered. We employed the various anesthetic agents at the concentrations used clinically preparatory for endoscopy. Previously at the Veterans Administration Medical Teaching Group Hospital (Kennedy), Memphis, Tenn., we have employed either 10 per cent cocaine or 2 per cent tetracaine for anesthesia prior to endoscopy. Presently, we are employing 5 per cent Cyclaine or 0.5 per cent Dyclone.

In the experimental laboratory, 20 healthy mongrel dogs weighing between 8.2 and 20 kilograms were used, one-half of which were unanesthetized and one-half were lightly anesthetized with intravenous sodium pentobarbital. All received the selected anesthetic agent intravenously in the concentrations

just listed at the rate of 1 c.c. per minute until dead. The end point of death was determined as the time of cessation of the heartbeat. The lethal dose for the various agents in milligrams per kilogram of body weight is shown in Table II.

TABLE II

AGENT	AVERAGE LETHAL DOSE		
	UNANESTHETIZED (MG./KG.)	ANESTHETIZED (MG./KG.)	COMBINED GROUPS (MG./KG.)
Cyclaine (6 dogs)	32.0 (3 dogs)	31.9 (3 dogs)	31.95
Dyclone (6 dogs)	12.9 (3 dogs)	11.8 (3 dogs)	12.3
Tetracaine (4 dogs)	11.0 (2 dogs)	6.2 (2 dogs)	8.4
Cocaine (4 dogs)	22.4 (2 dogs)	28.4 (2 dogs)	25.0

The picture appears different (Table III) when these same data are considered in volume of each agent per kilogram of body weight. Thus, to obtain a lethal dose in dogs, it required 3.8 times as great a volume of Dyclone per kilogram as Cyclaine, 5.9 times the volume of Dyclone as tetracaine, and 10 times the volume of Dyclone as cocaine. Cyclaine appears slightly less toxic (c.c./Kg.) than tetracaine and cocaine, but the difference here is not great, and the number of dogs employed was not large enough to be statistically significant. The comparison on the basis of cubic centimeters per kilogram is more valid because the various agents were used in the concentrations that are used clinically.

TABLE III

AGENT	AVERAGE LETHAL DOSE		
	UNANESTHETIZED (C.C./KG.)	ANESTHETIZED (C.C./KG.)	COMBINED GROUPS (C.C./KG.)
Cyclaine	0.64	0.65	0.65
Dyclone	2.6	2.4	2.5
Tetracaine	0.55	0.31	0.42
Cocaine	0.22	0.28	0.25

All of the unanesthetized dogs had strikingly similar responses following administration of these various anesthetics. All dogs exhibited marked salivation, urinary incontinence, generalized convulsions, and usually hyperpnea prior to cessation of respiration. In nearly all cases, respiration ceased a few seconds prior to the cessation of heartbeat.

In the anesthetized animals, pulse and arterial pressure were recorded by means of a catheter in the femoral artery connected to a mercury manometer and kymograph. Each cubic centimeter dose of Cyclaine, tetracaine, and cocaine produced in all animals an almost immediate marked fall in pressure that persisted for approximately 30 seconds following administration. Following Dyclone administration the pressure and pulse remained nearly constant until the lethal dose was approached at which time the pressure fell.

Salivation, urination, and convulsion were totally absent in the anesthetized animals. These animals did, however, exhibit hyperpnea just prior to cessation of respiration as did the unanesthetized dogs.

CLINICAL EVALUATION

Previously, patients who were to undergo endoscopy, bronchography, or dilatation of esophageal strictures were anesthetized with approximately 10 c.c. of a 10 per cent cocaine solution or a 2 per cent tetracaine solution. Approximately 7 c.c. of either agent was used to anesthetize the throat and larynx by applying the agent to the pyriform fossa with Jackson cross-action forceps. Approximately 3 c.c. of the remaining anesthetic was diluted with water to form solutions of 1 per cent and ½ per cent, respectively. The diluted anesthetic was then dripped between the vocal cords in aliquots of 1 to 2 c.c. until adequate anesthesia of the bronchial mucosa was obtained. Patients who were to undergo bronchoscopy or bronchography were instructed not to swallow any of the agent so as to minimize unnecessary absorption. If the patient was to undergo esophagoscopy or esophageal dilatation, small quantities of the diluted anesthetic agent were swallowed. Using this technique, adequate anesthesia was consistently obtained in over 6,000 successive endoscopies during the years 1943 to 1954, with no fatalities attributable to topical anesthesia. Serious untoward reactions were few; however, mild, disconcerting anesthetic reactions occurred in approximately 1 or 2 per cent of cases.

As a clinical research project, we started employing Dyclone for anesthesia in July, 1954, and Cyclaine in April, 1955. Fifteen cubic centimeters or less of either 5 per cent Cyclaine or 0.5 per cent Cyclone is employed by the same technique as described for the other agent. Since April, 1955, the nurse has set up the anesthetic trays and has alternated the anesthetic agents so that the endoscopist does not know which anesthetic he is employing until the examination is over. Since Cyclaine and Dyclone have been used we have performed 457 bronchoscopies, 67 esophagoscopies, 289 bronchograms, and 56 esophageal dilatations on 665 patients. Some of these patients were included in a previous report from this hospital on Dyclone topical anesthesia.[8]

Results have been satisfactory with both agents with respect to potency, promptness of action, and relative freedom from untoward reactions. The oxygen tank and the Pentothal syringe now go almost unobserved in the corner of the anesthetic room. After the completion of an examination, the endoscopist is permitted to learn what anesthetic he has employed on his preceding patient. By this method, the impression has been gained that Cyclaine becomes effective a little more promptly than Dyclone. However, the latter produces adequate anesthesia in about six minutes. Some examiners feel that Cyclaine gives more complete anesthesia. The duration of anesthesia with each agent is usually about 30 to 40 minutes which is adequate for most endoscopists. In indicated cases, the anesthesia is usually adequate for subsequent bronchography.

SUMMARY

From the data presented, it is apparent that, in dogs, intravenous Dyclone is appreciably less toxic than Cyclaine, tetracaine, or cocaine. Apparently Cyclaine in dogs is slightly less toxic than tetracaine and cocaine, but the difference is not great. Clinically, mild troublesome reactions are less frequent with these agents than they were when tetracaine and cocaine were employed.

Both Cyclaine and Dyclone produce adequate anesthesia in most patients for about 30 to 40 minutes. Further clinical use of these agents is warranted.

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CLINICAL SIGNIFICANCE OF OXYGEN REMOVAL

JOHN C. KOVACH, M.D.,* AND GEORGE MORALES, M.D.**
NEW YORK, N. Y.

ON our surgical cardiac patients, the routine preoperative work-up includes cardiac catheterization, residual lung capacity determination, angiocardiography, and spirometric studies. In the course of investigation, it has become evident that the oxygen removal is of special significance. A low value with no increase or a decrease on exercise may have ominous portent.

Two postoperative fatalities in young patients after pulmonary resection (lobectomy and pneumonectomy) who had had no apparent abnormalities beyond their pulmonary disease preoperatively, other than an abnormal oxygen removal, focused our attention on this entity.

The oxygen removal is the amount of oxygen in milliliters that is removed from one liter of respired air. The normal removal rate at rest is 40 ml. per liter of ventilation and at exercise is 60 ml., an increase of 50 per cent. Normal resting and exercise ventilation rates are assumed to be 5 and 15 L. per minute for an average man.

CLINICAL MATERIAL

To illustrate the various causes of a low oxygen removal, we have selected the following case histories. Table I summarizes the data in the order discussed.

The only abnormal feature of the first patient (L. L.) was a low oxygen removal, 34 ml. per liter of ventilation, which did not increase on exercise. Clinically, with all available evidence, she was considered to have a normal heart, there was no hyperventilation and there was a straightforward diagnosis of right lower lobe bronchiectasis without sequelae. The chest plate was essentially normal (no parenchymal disease). Preoperatively, the low oxygen removal which did not increase with exercise was commented upon but no reason could be given for it. She died on the seventh postoperative day. Our interpretation is that there was unrecognized right ventricular damage of which the only evidence was this low oxygen removal which did not increase with exercise.

The question might well be asked: what does a normal resting oxygen removal indicate in the presence of obvious parenchymal disease? Subject T. H., a 26-year-old Negro woman with tuberculosis, had a resting removal of 44 ml. which, however, decreased to 33 ml. on exercise. Our preoperative report was that she would not go through surgery due to right ventricular

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*Surgeon and Director of the Cardio-Pulmonary Laboratory of the City of New York, Queens Hospital Centre, New York, N. Y.

**Resident in Anaesthesia, New York University-Bellevue Medical Centre, New York, N. Y.

TABLE I

INITIAL	AGE	SEX	O_2 REMOVAL		O_2 CONSUMPTION		VENTILATION		DIAGNOSIS	V.C.	M.B.C.
			REST (ML./L.)	EXERCISE (ML./L.)	REST (ML./MIN.)	EXERCISE (ML./MIN.)	REST (LITERS)	EXERCISE (LITERS)		(MLS.)	(LITERS)
L. L.	30	F	34	31	268	495	9.5	15.7	Bronchiectasis of RLL	3057	78
T. H.	26	F	44	33	294	460	6.7	13.1	Tuberculosis of right lung	1449	47
V. L.	24	F	41	16	220	422	5.3	26.3	Pulmonary artery severance	1694	51
R. K.	30	F	37	22	276	369	7.4	16.6	Pulmonary embolus	2569	121
M. W.	63	F	31	19	278	380	9.2	20.1	Bronchogenic carcinoma	1910	70
L. H.	61	M	38	15	273	291	7.1	18.7	Carcinoma of left lung	2010	32
W. F.	70	M	53	80	409	1050	7.8	13.1	Carcinoma of pancreas secondary to lung	1334	38
B. A.	59	M	26	45	204	338	7.8	12.0	Benign teratoma	4030	80
R. J.	58	M	42	40	310	710	7.4	17.7	Carcinoma of LUL (Pancoast)	3850	60
B. A.	64	M	29	29	220	535	7.5	19.5	Renal carcinoma; secondary in lung		
R. E.	16	F	33	33	170	450	5.1	12.5	Benign ganglioneuroma	3240	102
R. B.	43	M	22	15	208	264	9.5	15.0	Mediastinal torsion		
T. D.	44	M	28	19	224	392	8.0	21.0	Tuberculosis of RUL; mediastinal torsion	2660	55
G. R.	51	M	19	38	200	527	10.7	13.6	Tuberculosis of LUL	3400	76
W. S.	43	M	25	27	224	430	9.0	16.0	Mitral stenosis		
D. A.	50	M	28	13	203	250	7.3	19.0	Mitral stenosis		
R. G.	46	M	26	27	224	317	8.3	11.6	Mitral stenosis		36
M. M.	50	F	22	17	201	238	9.0	13.9	Mitral stenosis and tricuspid insufficiency	1912	32
K. S.	51	M	33	54	213	510	7.0	9.5	Mitral stenosis and mitral insufficiency	2800	
M. A.	46	M	17	38	208	518	12.2	13.6	Aortic stenosis	3174	99
D. T.	46	F	22	23	222	296	10.9	13.0	Mitral stenosis and mitral insufficiency	2056	57

damage (unrecognized). However, her disease was primarily confined to one side and a pneumonectomy was carried out. She left the operating table with a tachycardia under O_2 of 150 beats per minute which persisted until her death some weeks later. The post-mortem report stated that the "heart is minimally enlarged as a result of minimal hypertrophy and dilatation of the right ventricle and right ventricular outflow tract; all other chambers were normal."

Due to an increased catabolism, her oxygen demands at rest were increased by 150 per cent (294 ml. per minute). This resulted in a relatively increased perfusion through the remaining healthy tissue which more than offset the effects of a diminished perfusion through diseased tissue. The one effect offset the other and a normal O_2 removal value was obtained. On mild exercise, even though the consumption increased to 460 ml. per minute, the removal rate decreased to 33 ml. per liter. This showed that she was at the end of her compensating ability and the right ventricle was unable to augment its output proportionately.

Obstruction of the pulmonary artery or of a large branch from any cause, resulting in ventilation of an unperfused area of lung, lowers the oxygen removal rate.

Subject V. L. shows the physiologic effects of accidental severance of the main right pulmonary artery during lobectomy. An attempt was made at re-anastomosis. The oxygen consumption and removal at rest and exercise point to severe pulmonary vascular deficiency on exertion rather than ventilatory insufficiency since she was able to ventilate at the rate of 26 L. per minute on exercise.

Pulmonary embolism and/or thrombosis for the same reason results in a low oxygen removal.

Subject R. K., a 30-year-old woman, had had a surgical procedure two years prior to study wherein she developed a pulmonary embolus. The oxygen removal at rest and exercise was 37 and 22 ml. per liter, respectively. The oxygen consumption was 276 at rest and 369 ml. per minute on mild exercise. Vital capacity and maximum breathing capacity were 84 per cent and 129 per cent of normal, in that order. This patient showed a partial residual vascular impairment. There were no other clinical findings such as pulmonary stenosis, right ventricular incompetence, etc., which also result in low oxygen removal rates.

One of the most important surgical causes of a decreased O_2 removal on exercise is the extrinsic pressure and/or invasion by hilar malignant node involvement of the pulmonary artery, vein, or its main branches.

Subjects M. W. and L. H. illustrate this phenomenon. At operation, all these cases were proved, personally by the author, to have extrinsic or intrinsic vascular obstruction. Both patients had preoperative bronchospirometric studies showing diminished oxygen uptake on the side of the lesion. The oxygen removal of Subject M. W. was 31 at rest and 19 on exercise and of Subject L. H. it was 38 and 15 ml. per liter.

The validity of the postulate is not affected by the fact that the bronchial arteries form bronchopulmonary anastomoses under pathologic conditions and take up a very considerable amount of O_2 if there is arterial unsaturation but

still drain into the pulmonary veins.[1] Pulmonary artery shunts to the bronchial veins also develop, but these too, have the same ultimate venous outflow. It should be remembered that the pulmonary artery pressure does not increase with exercise until the cardiac output is three times normal, such is the flexibility of the pulmonary vascular bed.[2-4] The pulmonary artery pressure will rise when the output is twice normal if one lobe is obstructed by malignant gland pressure, or one and one-half times normal if one main pulmonary artery is obstructed. It follows then, that on exertion there will be an increase in pressure (which varies with the degree of obstruction) to push by the obstruction and so tend to increase the oxygen uptake and removal of the involved area, while if the obstruction is fixed by actual invasion there can be no increase in oxygen uptake or removal by the involved lung. This point is brought out because of its bearing on the operability of a malignant lesion.

One further point is of extreme interest to the surgeon. The problem as to whether a "pulmonary malignant lesion" is primary or secondary in the lung in the presence of a negative bronchoscopy (with a doubtful Papanicolaou and a negative physical examination) can sometimes be decided one way or the other by the oxygen removal rate. If the removal is low it points to a primary lesion with large artery obstruction; if the removal is normal and, more especially if it increases with exercise, the lesion is metastatic and involves more distal finer terminal vessels by the peculiar virtue of the pathology of metastatic spread which does not affect oxygen removal because the large pulmonary vessels are free.

Subject W. F., a 71-year-old man, was admitted to the thoracic service with fluid in the right chest. This was tapped and a hydropneumothorax developed with a radiolucency in the right upper lobe and a partial atelectasis. Fluid block sections showed cells suggestive of malignancy. Supraclavicular nodes were enlarged and a negative biopsy obtained. Bronchoscopy was negative. Bone series and all other studies were completely negative for other sources of malignancy. The oxygen consumption and removal at rest was 53 ml. per liter which increased to 80 on exercise. The pathology report, four months later, was for carcinoma of the tail of the pancreas with spread to liver, lung, peritoneum, and pleura.

Subject B. A. is another example of a patient who had a nephrectomy for carcinoma seven years previously. He developed a right lower pulmonary malignant lesion and came to our thoracic unit with fluid as well on the right side. The oxygen removal was 29 ml. at rest and did not decrease on exercise. The absence of a fall on exercise is indicative of a metastatic type of pulmonary malignancy.

Another point of surgical importance should now be considered. If the problem lesion in the chest is benign; and most of them are problems until thoracotomy; (cystic, fibromatous, granulomatous, etc.), then they do not obstruct major vessels and the oxygen removal is relatively normal. What is more important is that the O_2 removal increases with exercise. If the oxygen removal is normal and especially if it increases with exercise one can state further that even if the lesion is malignant it is operable because it is of very limited extent.

Subject R. J., a 58-year-old man, had a large left upper lobe lesion as well as tuberculosis. The oxygen consumption at rest and exercise was 310 and 710 ml. per minute. The oxygen removals were 42 and 40, respectively. The preoperative cardiopulmonary report was "patient fit for resection. Studies suggest that this subject may have a resectable lesion if it is primarily pulmonary." Bronchoscopy was negative and the problem was to decide whether the lesion was a metastatic one (the appearance was suggestive of such) or, if primary, was it resectable? At operation, it was easily removed by an extrapleural resection. The pathology report was bronchogenic carcinoma.

In primary lesions of the mediastinum, the surgeon may infer, if the oxygen removal increases on exercise or remains the same (does not decrease) that the lesion is circumscribed or noninvasive such as would be the case in the lymphomas, cysts, neurogenic tumors, etc., whereas malignant lesions of comparable size cause a decrease in the oxygen removal on exercise.

Subject B. A., a 59-year-old man, had a tumor projecting from the mid-mediastinum and pericardium. The oxygen removal was 26 and 45 ml. per liter with an oxygen consumption of 204 and 538 ml. per minute at rest and exercise, respectively. At operation there was a tumor with a fan-shaped pedicle adherent to the pericardium in the mid-mediastinum with the phrenic nerve adherent to its posterolateral surface. The pathology report was benign teratoma.

Subject R. E., a 16-year-old girl, had a tumor mass in the mid-mediastinum projecting into the left chest. No definite preoperative diagnosis could be made. The oxygen consumption increased on moderate exercise from 170 to 415 ml. per minute. The oxygen removal did not fall on exercise. A 12 by 8 by 8 cm. benign ganglioneuroma "attached to retropleural and mediastinal tissues over a rather wide base and to the sixth intercostal nerve and sympathetic ganglia" was removed. There was "pressure erosion of the mid-dorsal vertebral bodies" and the mass was in the "left posterior quarter over the left hilum." Recovery was uneventful.

The effect of severe mediastinal shift and distortion on the pulmonary vessels is exemplified by Subject R. B. He had a right-sided segmental resection with a thoracoplasty as well as bilateral bronchiectasis. The oxygen removal was only 22 ml. at rest and 15 on exercise. A ventilation rate of 15 L. per minute on exercise demonstrated that he could ventilate and it was not merely dead space ventilation since there were neither localized nor generalized emphysema nor cystic areas. In certain cases, surgical means of correcting this severe physiologic impairment might be indicated.

A second example is T. D., a 44-year-old man, who had extreme tuberculosis retraction of the right upper lobe with mediastinal shift and normal remaining lungs. The oxygen removal went down from 28 to 19 ml. per liter on exercise with an oxygen consumption increment from 224 to 392 ml. per minute. Angiocardiography later showed a displaced superior vena cava and partial obstruction of the vessels on the right confirming the lung function findings. Lobectomy will improve this patient's vascular hemodynamics.

If there is no arterial unsaturation it should be pointed out that a non-ventilated lung, or portion thereof, automatically becomes nonperfused (the blood flow ceases to a nonfunctioning area of lung).[1] The converse of course does not follow. If there is sufficient parenchymal disease (and there must be enough to show up on a flat x-ray film) this, per se, will decrease the perfusion of the involved areas. If there is a corresponding amount of bronchial obstruction to ventilation or impairment through loss of mobility or flexibility of the involved parenchyma then there will be no change in the oxygen removal (both factors being affected equally). If, on the other hand, there is less loss of ventilation relative to the decrease in perfusion, then there will be a decrease in the oxygen removal.

Subject G. R. illustrates the point just discussed. His main disease (tuberculosis) involved the left upper lobe with some also in the right upper lobe. Angiocardiography showed an abrupt cessation of dye at the entrance to the left upper lobe and a partial obstruction to its flow to the right upper lobe at three and four seconds; as is so common in angiocardiography films, there was some overexposure but nevertheless there was no question about it. The oxygen removal was 19 ml. per liter at rest and 38 on exercise. This means that there was, at rest, ventilation of the nonperfused upper lobes. On exercise, he was able to increase the right ventricle output to transport 527 ml. of oxygen per minute and it followed that there were enough patent pulmonary arteries coursing into ventilating parenchyma to perform this function. The conclusion to be drawn from the pulmonary function study alone is that since the oxygen removal showed an even better than normal percentage increase with exercise the functioning portion of the total lung parenchyma was of normal function. The problem then was how much was normal lung tissue from a physiologic standpoint, as well as anatomically. The resting oxygen removal was one-half of normal, therefore one-half of the parenchyma was normal from both points of view. Since it had now been shown that one-half of the total lung tissue was of normal function, and thus was ample to sustain a satisfactory existence; the only remaining question was whether this physiologically competent lung parenchyma was situated in such a manner that it could be preserved. The x-rays and angiocardiograms, in addition to the function studies, confirmed that it could be preserved. There were about 5 L. of ventilation at rest per minute in the upper two lobes which were useless, and would be eliminated by their removal. On exercise the functionless upper lobe ventilation would also be done away with. The pulmonary artery pressures would be no higher after surgery than before because they were not perfused before. This patient will if anything be better from a physiologic point of view after bilateral upper lobectomy.

Last, the pulmonary studies pertinent to this communication of a few surgical cardiac patients are presented in Table I. These all show a diminished oxygen removal which may or may not increase with exercise, depending primarily on the myocardial reserve (vide infra).

Many of these patients (and we are dealing primarily with mitral stenosis cases here) are hyperventilating constantly due to visceroceptive reflexes arising

from the chronically stimulated alveolar capillary wall as a result of an increased pulmonary capillary pressure.[5] This in turn "blows off CO_2," which results in an increased sensitivity of the respiratory center in the floor of the fourth ventricle, because it results in the kidney releasing HCO_3 to lower the raised pH back to normal.* The renal loss of excess HCO_3 lowers the total ionic plasma content which increases the respiratory center sensitivity.[7, 8] Any slight increase in the intracellular CO_2 of this oversensitized respiratory center due to exercise will augment still more the respiratory rate. Since the resting cardiac output usually is a low normal or even less there is a high arteriovenous oxygen difference (low venous oxygen content) in the range of 7 to 10 volumes per cent. On exercise, due to the valvular disease, myocardial damage or lack of reserve, the output cannot be increased, and even may decrease, which, coupled with a resting low venous oxygen content, results in an inability of the hemodynamic mechanism to increase significantly the total oxygen uptake from the lungs. Thus, we have in exercise an increase in ventilation accompanied by a small or no increase in oxygen uptake. This shows itself as an oxygen removal on exertion equal to or less than that at rest.

The resting oxygen removal is low because of the aforementioned augmented visceroceptive stimulation causing hyperventilation in the face of a normal oxygen consumption. In cardiac disease, there is a normal total oxygen consumption and in fact the oxygen consumption per kilogram of myocardium is also normal (the efficiency, however, is down); as a matter of fact, even in the cardiac hypertrophy of hypertension there is no increase in oxygen consumption per kilogram of heart muscle mass.[9]

DISCUSSION

Right ventricular damage which may be unrecognized per se shows itself in pulmonary function studies as a diminished oxygen removal. This diminution is even more marked on exercise.

The first and second patients were used to illustrate this (L. L. and T. H.). The heart can neither maintain nor increase its oxygen removal rate on exercise even with a normal left ventricle.

Malignant lesions by virtue of intraluminal neoplastic invasion or unyielding extraluminal compression result in a decreased oxygen removal at rest which further decreases with exertion. Accidental ligation will, of course, produce a similar picture.

Pulmonary arterial obstruction from benign lesions do not cause a further decrease in the oxygen removal on exercise because the increased ventilatory movement on exertion together with the increased cardiac output is able to effectively by-pass this "benign obstruction" and the oxygen removal increases with exercise. Secondary pulmonary metastatic lesions act similarly through the peculiar pathology of their method of spread. They first grow near small vessels and so do not obstruct much of the blood flow.

*There is recent work which may modify the present usually accepted description of a "compensated respiratory acidosis" as one in which renal NA^+ and HCO_3^- retention offsets an increased PCO_2 blood level.[6]

Extreme shift of the mediastinum with tension and deflection of the vena cava or pulmonary arteries also results in a diminished oxygen removal which decreases still further with exercise. The cause is usually obvious however, e.g., large aneurysm, thoracoplasty, and localized pulmonary contracting fibrosis. The inflexibility of the causative agent results in this phenomena.

Parenchymal disease affects perfusion and ventilation proportionately so that the oxygen removal does not change with exertion even if it is somewhat decreased at rest.

Last, cardiac patients with valvular disease have a diminished oxygen removal at rest. The change with exertion depends upon whether they are in low or high output failure, if in failure, if not, then it depends upon the myocardial status, right or left, or both.

The test is very easily done and when interpreted to its full extent is very helpful in diagnosis, and as part of a study to assess cardiopulmonary function since it depends upon both. Psychogenic hyperventilation has been no problem with us.[10]

SUMMARY

The cardiopulmonary studies of a variety of surgical subjects, with particular reference to the oxygen removal rate, are presented.

The value in diagnosis is pointed out with confirmation of its interpretation.

The oxygen removal is diminished at rest and decreases still further on exercise in carcinoma with "inoperable mediastinal spread."

The oxygen removal does not decrease with exercise in benign lesions and metastatic peripheral pulmonary lesions.

Valvular disease and right- and/or left-sided myocardial disease also cause a decreased oxygen removal at rest. The reaction to exercise varies with the status of the myocardium and hemodynamics. The oxygen removal is a good index of the myocardial reserve.

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A PROSTHESIS TO REPLACE THE MITRAL VALVE

M. C. Kernan, M.D., M. M. Newman, M.D., B. S. Levowitz, M.D., J. H. Stuckey, M.D., and C. Dennis, M.D., With the Technical Assistance of Alva Riddick and Herbert Lauritzen
Brooklyn, N. Y.

AT PRESENT, there is no good surgical treatment for severe mitral insufficiency, especially for that secondary to severe calcification of the mitral leaflets or destruction of chordae tendineae. Experimental work on dogs has shown that the mitral valve can be replaced completely by a plastic prosthesis. To our knowledge, the only previous artificial mitral valve which has permitted prolonged survival is that reported by Denton.[1]

METHODS

Dogs weighing 17 to 25 Kg. were anesthetized with intravenous pentobarbital. A cuffed, intratracheal tube was inserted and ventilation begun with the Jefferson Respirator* with 100 per cent O_2. The left chest was entered through the bed of the fifth rib. The left subclavian artery was isolated. The pericardium was opened transversely from the reflection over the left pulmonary veins to well over on the right side, the phrenic nerve being dissected free and retracted laterally.

Heparin was given intravenously at this point. Prior to perfusion the heparin level in the blood used to prime the extracorporeal circuit averaged 60 mcg. per milliliter (heparin†) as measured by titration with protamine sulfate (1 per cent solution N. F.‡). This level in the priming blood resulted from the addition of 25 mg. of heparin to each liter of blood drawn.

The subclavian artery was ligated where it gave off the vertebral artery and was divided. A No. 14 Fr. polyvinyl catheter was inserted through the proximal stump to just within the aorta or slightly into descending aorta. A No. 28 Fr. catheter was secured in the right atrium by a purse-string suture in the atrial appendage in the last 16 dogs instead of encannulating each vena cava. The pump-oxygenator was attached to the arterial and venous channels. Technical details of the artificial heart-lung have been described previously.[3, 4]

The valve is shown in Fig. 1. It is a Teflon shell, housing a solid methyl methacrylate sphere,§ 15.5 mm. in diameter. This design for a ball valve

From the Department of Surgery, State University of New York College of Medicine.

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†Supplied by Connaught Laboratories.

‡Supplied by Eli Lilly Company.

§Lucite spheres obtained from Ace Plastic Company, 91-30 Van Wyck Expressway, Jamaica, N. Y.

In two animals, nylon balls were used.

(M.M.N.) was chosen for our initial experiments because of its mechanical simplicity, ruggedness, ease of insertion and fixation in the mitral annulus, and ease of manufacture in our shop.*

The technique finally evolved was this: The animal's circulation was connected to the pump-oxygenator. Part of the blood flow at this time still passed through its own heart and lungs. In 23 dogs, ventricular fibrillation was initiated with a shock of 6 volts 60 cycle AC through two closely spaced electrodes applied to the ventricle. Fibrillation occurred spontaneously in 2 animals. A few seconds later an incision, 3 cm. long, was made from the midpoint of the left auricular appendage to a point past the pericardial reflection on the left inferior pulmonary vein. A small vein retractor was inserted to retract the

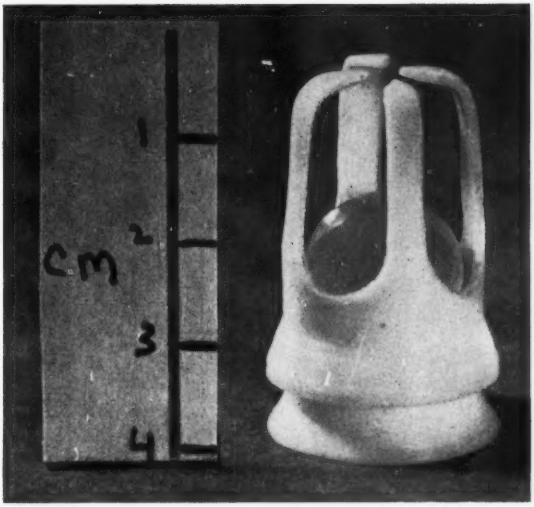


Fig. 1.—Mitral valve prosthesis.

auricle anteriorly to expose the mitral valve; traction on the auricular appendage was also essential for good exposure. Blood in the field was removed by continuous suction to a sterile bottle for possible later re-introduction into the circulation. A continuous purse-string suture of No. 2 braided silk was introduced in such manner that suture bites passed through the elastic tissue of the mitral annulus. Chordae tendineae to both mitral leaflets were then divided and, occasionally, portions of the valves were excised to remove any obstructions to the prosthesis entering the left ventricle. The valve was slipped into position and the heavy silk purse-string suture was tied into the groove around the base of the valve. The auricle was then allowed to fill with blood and all air was displaced from the left ventricle. The auricular incision was closed with two layers of continuous, Atraumatic No. 5-0 silk.

*We are indebted to Mr. Ludwig Quabeck for the precision work on the pump-oxygenator and on the valves.

The heart was massaged a few times to relieve any distention of the right ventricle. Defibrillation was usually accomplished with one or two shocks of about 2 amperes of 0.1 second duration. A loud systolic click marked onset of strong left ventricular contraction.

The chest was drained through tubes in the right and left sixth interspaces. The periosteal bed and muscles were closed in layers with interrupted silk.

RESULTS

The procedure described was performed on 25 dogs. The first 7 were considered as pilot studies. Three died during operation and 4 within the first six hours, postoperatively. In 4 of these dogs, the mitral valve was approached through the left auricle and the prosthesis fixed with interrupted sutures. A ventricular incision was used in 3 dogs with fixation by interrupted sutures in 2 and a circumferential suture in one. All 3 dogs with ventricular incisions died in one and one-half hours or less.

The remaining 18 dogs were all operated upon by essentially the same technique: a left auricular approach and a purse-string suture around the annulus for fixation. There were five fatalities during the first 48 hours postoperatively, 12 dogs lived 48 hours to 3 weeks, and one died 4 months after insertion of the prosthesis (Table I).

TABLE I. SURVIVAL TIMES AND CAUSES OF DEATH
PLASTIC MITRAL VALVE

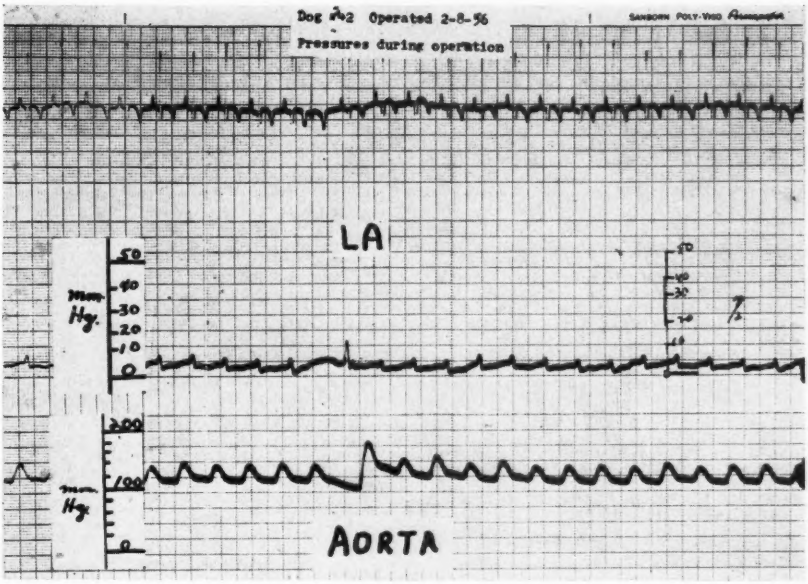
CAUSES OF DEATH	NUMBER OF DOGS	DURATION OF SURVIVAL
Technical error	3	Less than 48 hours
Hemorrhage	2	Less than 48 hours
Thrombosis on purse-string suture and fatal emboli	5	2 to 21 days
Displacement of valve (nonfatal emboli also present)	5	2 to 21 days
Extrusion of ball	2	4 days and 4 months
Occlusion of valve by thrombus	1	10 days

Intra-auricular pressures, recorded before the auricle was opened and after the valve had been placed, show the absence of regurgitation (Fig. 2 and Table II). However, a minimal amount of opacification is seen on motion pic-

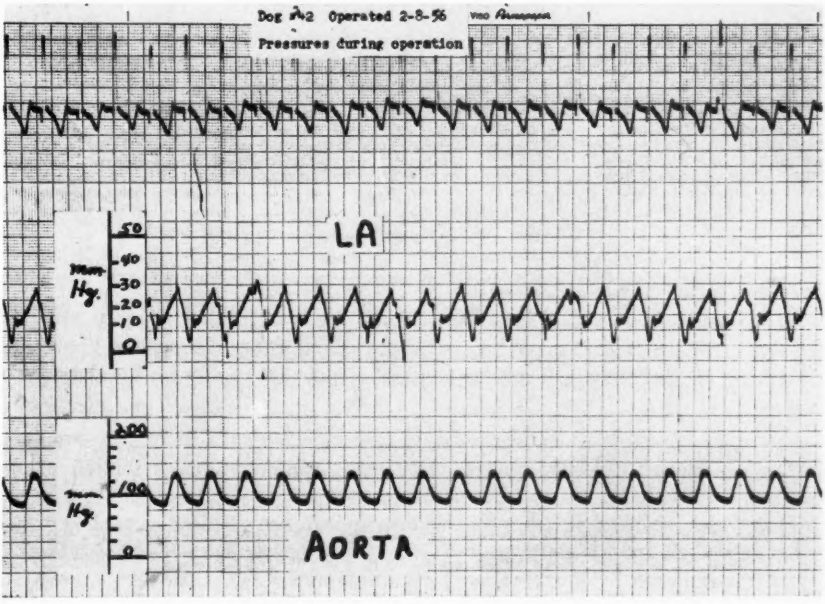
TABLE II. AURICULAR PRESSURES

DOG NUMBER	BEFORE (MM. HG)	AFTER (MM. HG)
544	7/0	20/10
27	5/0	18/3-5
32	8/0-2	20-22/2-4
42	7/2	30/5-15
Wedge Pressures		
591		18/0
587		20/0

ture cardiograms in which dye was injected directly into the left ventricle. The tracings do show moderately elevated intra-auricular pressures during auricular systole. When tested outside the heart, the valve seemed to produce minimal obstruction to flow: a 10 cm. head of pressure produced a flow of more than 20 L. per minute.



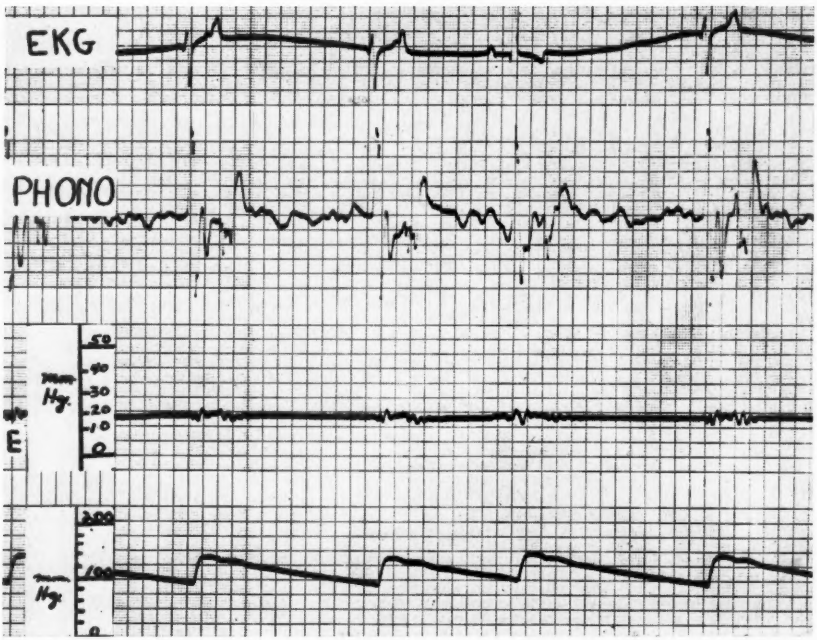
A.



B.

Fig. 2.—Pressure tracings in the left auricle taken during operation, before and after insertion of the prosthesis. Dog No. 42. *A*, Before insertion. *B*, After insertion. (*Fig. 2 continued on pp. 702 and 703.*)

The control clotting time averaged 12 minutes while postperfusion it was 15 minutes. The control pCO_2 was 39 mm. Hg average and postperfusion was 23 mm. Hg. The mean perfusion arterial pressure was 68 mm. Hg. The average arterial saturation was 96 per cent and flows averaged 39 c.c. per kilogram per minute.



C.

Fig. 2 (Cont'd).—*C*, Pulmonary artery. Dog No. 59.

DISCUSSION

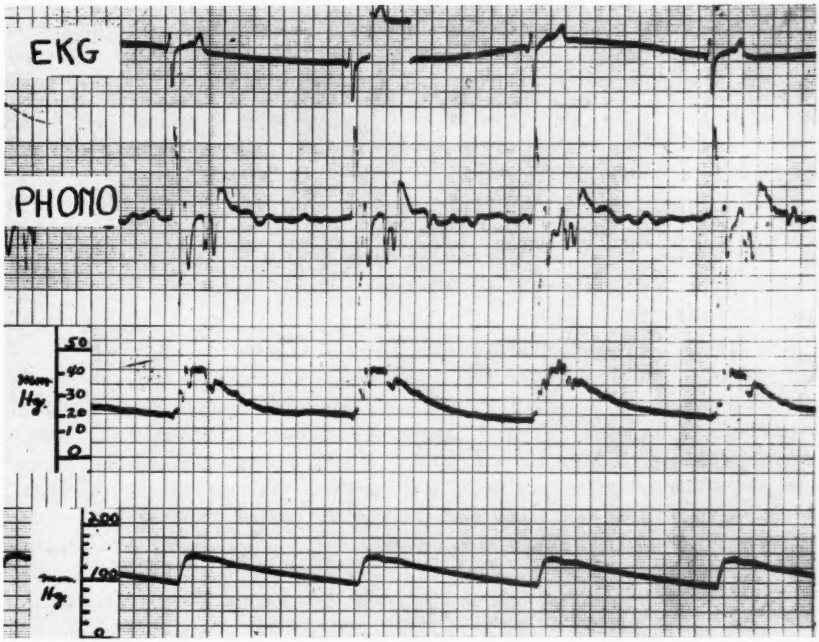
Attempts to correct mitral insufficiency can be divided roughly into two groups: reconstructive procedures on the valve proper, and those operations in which an additional substance is used to support or replace the distorted valve.

The first recorded plastic procedure to correct mitral insufficiency was performed in dogs by Alexis Carrel.[5] He performed a partial resection of the wall of the left ventricle just below the coronary artery with a plication of the defect which reduced the size of the mitral annulus. This dog survived—for what period of time is not known. Successful experimental work of a similar type was reported by Hurwitt, Hoffert, and Ferreira.[6]

Recently, Davila, Mattson, O'Neill and Glover[7, 8] have shown the results of decreasing a dilated atrioventricular ring by a purse-string suture placed externally. Another method of decreasing the diameter of the annulus is to place

a double suture of silk or pericardium at the aortic-auricular junction, passing through the valve and out the anterior and posterior walls of the atrium.[9]

Bailey and his associates[10, 11] have reported use of a noose of pericardium inserted through the ventricle and across the posterior commissure. Also pericardial strips have been used by this group as artificial chordae tendineae for placement between the valve cusp and ventricular wall.



D.

Fig. 2 (Cont'd).—*D*, Wedge pressure taken one month postoperatively. Dog No. 59.

Any procedure modifying the valve structure or ring is applicable only where the structures are pliable and not calcified or where the loss or distortion of tissue is not too great. Correction of a defect requires additional material which is usually placed beneath the valve. Such defects usually occur in the posterior commissure or central portion of the valve. It would be most desirable to have the prosthesis at right angles to the defect to obtain optimal function and to avoid the papillary muscles and chordae. However, this is impossible since the axis would traverse the interventricular septum and aorta. This method, therefore, has great disadvantages no matter what material is used.[12]

Although not fixed in an ideal position, autogenous grafts such as inverted veins, tendons, free and pedicled strips of pericardium have all met with initial success when used as transventricular slings. It became clear that failure of these materials to retain their original form was due to chronic inflammatory

changes which were thought to be a result of the avascularity of the transplanted tissue.[13-16] Attempts were made to remedy this by inverting a piece of vein over internal mammary artery, but without much success.[17] A nylon ball within a tube of pericardium, used as a sling, failed ultimately for the same reason: avascular changes which would in all probability have led to embolization of the ball.[18]

The auricular appendage has been used to fashion an additional valve by invaginating it or anastomosing it to the ventricular wall, but again long-term results have been unsatisfactory.[1, 19, 20]

A somewhat different approach has been the bottle-shaped Lucite baffle used by Harken,[21] the Ivalon baffle of Johns and Blalock,[22] and the Lucite ball attached to the posterior wall of the left ventricle.[21, 23, 24] These prostheses are at best limited in application and unpredictable in outcome.

Still another type of replacement, made of spring steel (''Elgiloy'') and nylon, has been used experimentally with little success by Jordan and Wibble.[25] Inserted through a trocar in the left ventricular wall, the nylon-covered steel springs apart at a 45 degree angle, bridging a defect in the posterior commissure with each systolic thrust.

Hufnagel[26] has shown that a plastic prosthesis in the descending aorta can successfully substitute for a severely insufficient aortic valve. To replace the mitral valve with an intracardiac prosthesis is a more formidable undertaking and yet seems the most universally applicable solution. Criteria which such a prosthesis must meet are: the valve must (1) be mechanically efficient—there must be no stenosis or regurgitation, (2) be of a stable and durable material, (3) interfere little or not at all with ventricular contraction, (4) be well tolerated by tissues, (5) be simply and securely anchored, (6) be free of clotting, and (7) be adaptable to a wide variety of clinical situations.

In 1950, Denton, Mastriani, Brown, and Wiggers reported the successful replacement of the mitral valve by a rigid polyethylene prosthesis sutured into the mitral ring.[27] This was rounded on its ventricular end with either a straight tubular opening or a side opening which was closed by ventricular contraction. The longest survivors lived four to five months. Denton[1] has since reported extensive experimental work with this type of valve. Anchoring the prosthesis proved to be so technically difficult and displacement of the valve was so common, that this approach to mitral valve replacement has been abandoned.[2]

The Teflon and Lucite valve developed in our laboratory has proved to be a mechanically efficient, rugged replacement. Teflon was selected for the casing because it possessed high tensile strength, chemical inertness, and low wettability. Polished Lucite spheres were used because they are unlikely to promote clotting.

Following the extensive work of Senning[30] and Glenn and Sewell,[31] ventricular fibrillation has been shown to be a completely satisfactory way of preventing air embolism, which is a particularly great hazard in surgery on the left side of the heart. Another advantage of fibrillation is that of better visualization and easier manipulation in a still heart. We have had no difficulty in defibrillating a heart which has been well oxygenated during adequate perfusion.

The portion of the valve projecting into the left ventricle undoubtedly injures the ventricular wall and septum during each ventricular contraction. In some animals, we have seen small subendocardial hematomas and scarring. The desirability of eliminating this constant source of trauma is recognized, and will be considered in future designs.

The purse-string suture securing the valve has not been satisfactory for long-term survival except in one dog; although it has allowed opportunity for testing other characteristics of the prosthesis. Various other fixation techniques are being tried.

CONCLUSIONS

1. A prosthesis consisting of a Teflon casing and Lucite ball has been developed to replace the mitral valve in dogs.

2. Using a pump-oxygenator and ventricular fibrillator, we have successfully inserted the valve in 18 dogs in which mitral regurgitation had been created by severing chordae tendineae and by partial amputation of mitral leaflets.

3. Survival times have varied from a few hours to 4 months. The longer-term survivors have not appeared to suffer exercise intolerance.

4. The related problems of fixation and thrombus formation at the zone of fixation must be further investigated before this mechanically satisfactory ball valve can be adapted to clinical use.

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